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TIN ORES OF CHOCAYA, BOLIVIA.[1]

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INTRODUCTION.

THE purpose of the present paper is to describe briefly a suite of tin ores collected in the summer of 1921 by Dr. Waldemar Lindgren. In reference to the general features of the occurrence of the ores, Dr. Lindgren has been kind enough to furnish us with the following statement:

The tin and silver district of Chocaya is situated in southern Bolivia in the Department of Nor Chichas, about 100 kilometers from the Argentine boundary. It is 45 kilometers southeast of Uyuni and connected by railroad with this center. Topographically it is located in the Eastern Cordillera which here, however, is rather a tableland than a mountain range. The elevation of the mines is about 4,220 meters, that of the railroad station 200 meters less. The elevation of Uyuni is 3,700 meters.

From the broad playa and salt flats of Uyuni the road rises gradually to a broad, low divide covered with rhyolite flows; a sharp descent of 300 feet carries the railroad down into the Pilcomayo drainage and the track continues in a shallow, gradually deepening valley, bordered by rhyolite bluffs. Weathered slates of Paleozoic age begin to appear in the valley at the Chocaya railroad station. The mines lie in an open valley, the lower part of which is deeply incised in the rhyolite.

At the camp, a couple of miles from the station, are concentrating works. The mines are higher up among a landscape of yellow rhyolite bluffs. There are two principal mines. One is mined by the Compañia

[1] Since the preparation of the manuscript, the general geologic relations of the deposit have received treatment at the hands of F. R. Koeberlin. See *Eng. & Min. Jour.-Press*, April 17, 1926, pp. 637 and 641.

Aramayo de Minas and is locally referred to as "Las Animas." The other, more northerly, is near the camp and operated by the Compañia Minera y Agricola de Oploca, and is referred to as the Oploca mine. The two companies are operating on the same vein which, however, differs materially in the two properties.

The vein is contained in the rhyolite flows, is 2 to 3 kilometers long, strikes N. 26° E., and dips steeply. The average width of the Las Animas vein is about 60 centimeters, that of the Oploca perhaps 2 meters.

Both properties produce silver and tin; Las Animas containing chiefly silver. The ore is rich, averaging about 100 ounces of silver and 7 per cent. of tin to the ton. The Oploca ore carries more cassiterite, but has also one well-defined silver shoot.

The Las Animas mine is developed by a tunnel and a shaft 125 meters deep, probably deeper now. The ore is beautifully banded, but the banding is not parallel to the walls, but rather surrounds fragments of rock contained in the vein. The richest level was probably 125 meters below the tunnel. The cassiterite is recovered, but the tin in the stannite is a complete loss. The Oploca Mine is connected with the Las Animas by a 1,000 meter drift; the ore largely forms concentric bands of pyrite and cassiterite about rounded fragments of partly replaced country rock. The difference in mineralization is explained as probably having been caused by a split or branching of the vein between the two mines. North of this split there is very little silver in the ores.

The collection contains specimens taken from both the Las Animas and Oploca sections of the vein. While a somewhat more detailed discussion will be given presently, it will facilitate matters to include here a brief description of the suite.

The specimens from the Oploca section of the vein include samples of the wall rock, of the main part of the vein and from an ore-shoot containing high values in silver. Those from the main part of the vein exhibit banding and are composed almost entirely of pyrite, quartz, and cassiterite. In two of these, the banding is arranged concentrically about small cores, giving rise to an appearance (see Fig. 1) similar to that of orbicular igneous rocks. Beyschlag, Vogt, and Krusch[2] apply to this structure the terms "cockade" or "concentric." Another specimen (see

2 Beyschlag, F., Vogt, J. H. L., and Krusch, P.: "The Deposits of the Useful Minerals and Rocks." Translated by S. J. Truscott. Vol. 1, p. 114. MacMillan & Co., London, 1914.

Fig. 2) shows banded structure but the arrangement is more layer-like than concentric.

The specimens from the silver-ore shoot are massive in structure.

Banded structure is also displayed in the samples from the Las Animas section of the vein. In these, however, the bands are coarser and somewhat less regular than those of the specimens from the Oploca section (see Fig. 3), and sulphide minerals, such as stannite, and tetrahedrite are important constituents.

COUNTRY ROCK.

While unaltered samples of the country rock were not available, it will be of interest to present briefly a description of the altered wall rock.

As seen in the hand specimen, the rock is a gray porphyry with numerous small feldspar phenocrysts and less numerous, but somewhat larger ones of quartz. Quartz seams cut across the rock in connection with disseminations of pyrite.

In thin section, the rock appears highly altered and original minerals are almost lacking. The groundmass is quite silicified. The feldspars are entirely replaced by a network of sericite foils. Biotite has been bleached to clear shreds with intercalated bands of shapeless rutile. In apparently advanced stages, it is replaced by a delicate, often radial, growth of a fibrous mineral (a serpentine?). Zircon prisms, usually associated with the altered biotite, and quartz phenocrysts alone retain an unaltered condition. These rounded quartz phenocrysts contain, among other inclusions, an isotropic mineral of low index, probably fluorite, which occurs as linear strings of minute specks and larger individuals of diamond-shaped cross section.

Pyrite crystals are abundantly scattered throughout the rock, but appear somewhat segregated about seams of interlocking quartz crystals. Such seams contain rare small crystals of cassiterite.

OPLOCA SPECIMENS.

The cockade structure is displayed in the form of irregularly oval shells, concentrically arranged about a core (Fig. 1). The cockades vary in size from a quarter of an inch to two inches and consist of as many as ten distinctly defined shells of alternating minerals. The outer shell is always of quartz which, in the free cavities often occurring between cockades, forms drusy coatings. The cores are, in general, of altered country rock in various stages of replacement by the vein minerals; the structure is, therefore, a concentric deposit on a rubble of fragments of country rock. The vein minerals are pyrite, cassiterite, and quartz, in order of their relative quantities. They are distinctly crystallized, the quartz and pyrite often exhibiting forms which may be identified. In size the crystals vary from microscopic dimensions to individuals one sixteenth of an inch across.

A thin section of part of a cockade is shown in Fig. 4. Some of the quartz was undoubtedly deposited in the colloidal state. In such grains, extinction of the crystallized aggregate is normal to regular strings of inclusions, each string being concentric with the outer, usually rounded, boundary of the grain. Cassiterite associated with this colloidal quartz would appear, on first examination, to be also a recrystallized gel. It has a fine texture with individual crystals developed normal to the banded structure. Alternating light and dark bandings apparently are continuous across such crystals. Careful examination with high magnifications, on the other hand, reveals that the darker banding is due to a more intense pleochroism, which ordinarily is from yellowish to colorless or somewhat greyish. These more pleochroic zones do not cut indiscriminately across individual crystals, as in the case of regularly arranged concentric inclusions in colloidal quartz, but appear in slightly different positions in contiguous crystals. This would seem to suggest that the cassiterite crystals were deposited directly from solutions rather than recrystallized from a gel. If this is the case, the variation in intensity of pleochroism may be attributed to a difference in iron content of various parts of the same crystal, and in this we see a fluctuation in the character of the depositing solutions.

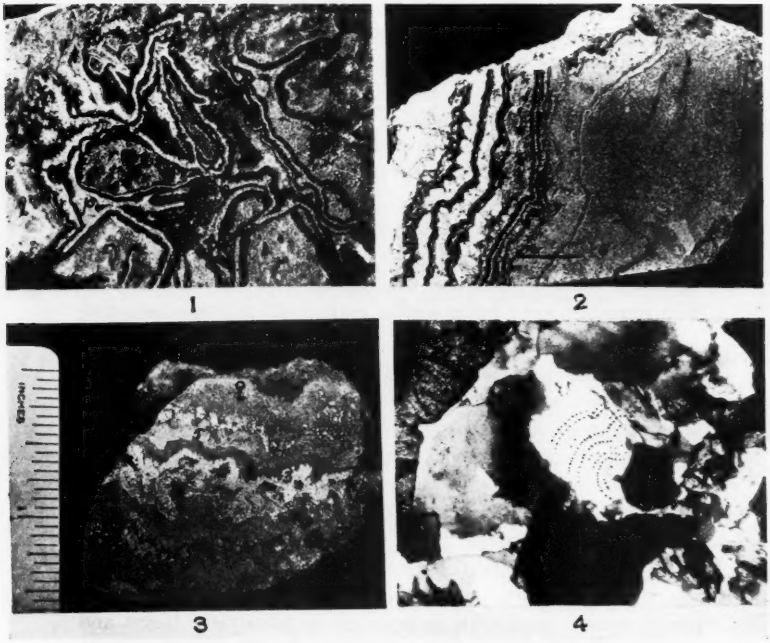

FIG. 1. Portion of polished face of a specimen of cockade ore from the Oploca section of the vein. × 1.1. *c*, cassiterite with quartz; *p*, pyrite; *q*, quartz druse; *r*, altered country rock cores.

FIG. 2. Polished face of a banded specimen from the Oploca section of the vein. × 1.1. Dark bands, cassiterite and quartz; light bands, pyrite; *r*, highly altered rock; *s*, thin stannite bands.

FIG. 3. Polished face of a banded specimen from the Las Animas section of the vein. Numerals refer to bands listed in text. Bands 6 and 7 are here represented only by the quartz druse *q*.

FIG. 4. Part of a thin section of a cockade, showing colloidal quartz. Note central colloform mass with concentrically arranged strings of inclusions. The faint but distinct inclusions have been inked over. Crossed nicols, × 67. Black, pyrite; dark, high relief, cassiterite; white and shades of gray, quartz.

Thin sections show, among the rarer constituents of the cockades, the presence of irregular hematite flakes and bits of some unidentified, colorless, isotropic mineral having an estimated refractive index of about 1.65.

In determining the sequence of formation, the assumption was made that the growth of the cockades took place from the core outward, and that, therefore, the earliest mineral in the inner band was the earliest of the series.

The paragenesis of the vein minerals was studied on a large polished hand specimen (Fig. 1) and several individual polished cockades. The cores display various stages of replacement by the vein minerals, some being almost entirely of pyrite, others containing only traces of scattered pyrite and quartz. In most cases these minerals are arranged in distinct veinlets, within which the pyrite occurs as corroded residual strings, while the evidently later quartz is continuous with the inner quartz-pyrite band.

The first band of the cockades is essentially pyrite and quartz with subordinate amounts of cassiterite. The pyrite has been extensively replaced by quartz, the latter often veining it. The second band is of cassiterite, which molds itself upon certain remaining euhedral faces of the pyrite and also, to a minor degree, replaces both quartz and pyrite. This established sequence: pyrite, quartz, cassiterite, is repeated in subsequent bands and often three distinct cycles are represented. Specks of stannite occur in the second pyrite band.

Fig. 2 shows another type of specimen from the Oploca section of the vein, which may be interpreted as a display of crustification on the vein wall. One-half of the specimen consists of an intimate mixture of fine-grained pyrite, quartz, and the remains of the altered country rock. The rest of the piece is a series of comparatively narrow bands, varying from three eighths of an inch to a very slight width. The minerals constituting these bands are pyrite, quartz, cassiterite, and stannite. The latter often carries minute blebs of chalcopyrite and tetrahedrite. The majority of the darker bands shown in the figure are composed of both quartz and cassiterite, either in separate, smaller bands,

or intermixed. The lighter bands are the metallic minerals. A noteworthy feature connecting this deposition with that of the cockade ore is found in the alternation of two thin bands of stannite with the first three of pyrite. In the cockades, stannite only appeared as occasional pieces in the second pyrite band.

SPECIMENS FROM THE SILVER-ORE SHOOT.

The specimens from the silver-ore shoot are characterized by the absence of banded structure and the presence of numerous small vugs containing well crystallized minerals. Pyrite, stannite, tetrahedrite, quartz, galena, sphalerite, cassiterite, jamesonite, matildite (?) and the unidentified mineral previously mentioned, are represented in the ores.

In all specimens pyrite, quartz, and cassiterite are the oldest minerals. In polished sections, the other minerals are seen to be molded about the crystal outlines of these earlier ones, which usually show corroded edges. Occasionally some replacement is shown, particularly of quartz by sphalerite.

In specimens containing sphalerite and galena, quartz is most abundant, and the later minerals display a curious concentric arrangement. Within rudely polygonal spaces in quartz are found sphalerite, stannite, and galena, the last forming the center. Examination with high magnifications shows that the stannite is replaced by the sphalerite and galena, the former sending minute anastomosing apophyses into it. In other parts of the same specimens galena replaces sphalerite, apparently following cleavage directions, leaving scalloped and veined residuals. The process indicated is one of combined filling and replacement. The stannite first deposited in interstices between quartz crystals. Subsequently sphalerite replaced both quartz and stannite along contacts, forming a ring between these minerals closely simulating the outline of the original opening, and still later galena replaced the core of the stannite forming the center. Tetrahedrite is very inconspicuous but high powers reveal rare shreds of it in galena.

In most specimens, however, galena and sphalerite are absent.

In these the stannite contains more abundant streaks of obviously later tetrahedrite. Associated with these are somewhat lath-like or streaked areas of a doubtful galena-gray mineral of low hardness, which is negative to all Davy-Farnham [3] reagents.

Blowpipe tests on pieces of stannite containing no other inclusions (except possibly small blebs of tetrahedrite) give indications of bismuth and silver. The presumption is strong, therefore, that we are dealing with matildite, which would account, in part, at least, for the high silver values of the ore in this shoot. No native silver or other silver-bearing minerals were found here.

The final phase of mineral deposition is shown by tufts of acicular and bladed jamesonite supported on crystals of quartz, tetrahedrite, and corroded pyrite. Polished section study proves that both tetrahedrite and pyrite are well along in the process of replacement by this late mineral.

THE LAS ANIMAS ORE.

The ore from this part of the vein exhibits a rough banding of minerals. The specimens will probably bear a somewhat detailed description. In two of these, the banding from the wall outward is (Fig. 3):

(1) A broad band of cassiterite, quartz, and pyrite. The first two are intimately intermixed while the pyrite occurs as scattered grains, often clearly veined and corroded by the cassiterite. In some cases the minerals exhibit a very interesting structure. About apparently earlier pyrite grains are arranged delicate, alternating bands of cassiterite and more pyrite in such a manner as to often reproduce in the entire structures, the outlines of the original nuclear grains. This effect of banding about a nucleus on a small scale may be correlated with the banding in the cockades. The identical mineralogical, and similar structural relations may be accepted as evidence of similar conditions, possibly contemporaneity, of deposition of these phases.

[3] Davy, W. M., and Farnham, C. M.: "Microscopic Examination of the Ore Minerals." McGraw-Hill, 1920.

(2) A discontinuous band of tetrahedrite with a little stannite, replacing some of the outer pyrite grains of the preceding band.

(3) A thin band of pyrite, with crystal outlines directed toward the following band.

(4) Minutely banded quartz of almost chalcedonic appearance, containing darker bands of cassiterite which conform with the general colloform structure, molded upon the euhedral pyrite faces of band 3.

(5) A broad, rather ill-defined band of practically pure stannite, bordered by small pyrite grains. This grades into:

(6) An intimate mixture of quartz, stannite, chalcopyrite and tetrahedrite, grading into:

(7) A wide band of tetrahedrite, often terminating in large crystals. In one specimen these last two bands are missing and in their place is drusy quartz.

While definite age relations can be established within an individual band, these are complicated by the various generations of any particular mineral and by the indefinite boundaries of most of the bands.

In polished sections, age relations between various minerals are, in general, the same, regardless of the band studied. In tetrahedrite-stannite bands, quartz and pyrite are found to be the earliest minerals, displaying crystal outlines which are often corroded next to the later minerals. Chalcopyrite sometimes replaces pyrite. It is in turn veined on a very minute scale by delicate threads of stannite and tetrahedrite. Some small patches of chalcopyrite, however, seem to bear some relation to irregular cracks and late quartz veins in tetrahedrite and stannite, but the greater part of it, at least, is earlier than these minerals. Although tetrahedrite and stannite usually occur in separate blocky masses, certain definite pinching and swelling veinlets of tetrahedrite are found cutting stannite. These minerals are invariably associated with rich silver values which are to be accounted for by numerous microscopic inclusions of native silver and matildite, which often occur together. The matildite has a

streaky, veinlike habit, apparently veining tetrahedrite and stannite, while the silver ordinarily forms shapeless blebs or more rarely isolated lozenges. These are taken to be the latest minerals present and appear to be hypogene. It is noteworthy that the presence of silver values is confined to tetrahedrite-stannite bands and is absent in pyrite-quartz-cassiterite bands. This is in harmony with, and explains, the absence of rich silver values in the cockade ore of Oploca.

Viewed broadly, the general features suggest that an overlapping deposition has ensued, without extensive replacement of one mineral by another. The sequence of minerals[4] appears to be: Pyrite, quartz and cassiterite—earliest; chalcopyrite; stannite; tetrahedrite; matildite and silver.

In an early band of one Las Animas specimen, arsenopyrite occurs in crystal clusters surrounding earlier corroded masses of pyrite. Later, somewhat massive bands are rich in chalcopyrite, and the same sequence of completion of crystallization is observable as already noted. The process suggested by examination of polished sections is essentially a filling, by later minerals, of spaces existing between earlier ones. This is borne out by the fact that stannite, with a discontinuous tetrahedrite selvedge, forms a final, thin, regular coating covering the entire massive band itself, apparently depositing there after having filled all the available interstitial space.

CONCLUSIONS.

The deposit occurs in connection with rocks of acid composition and while it is not to be supposed that the rhyolite was directly connected with its formation, it seems highly probable that the vein was genetically connected in depth with a parent chamber of acid magma.

In considering the mechanics of origin of this deposit, let us first eliminate the possibility of its formation by means of the injection of an "ore magma." Had such an hypothetical "ore

[4] Frankeite and cylindrite are also mentioned from Las Animas by A. W. Stelzner, "Die Silber-Zinnerzlagerstätten Bolivas." *Zeit. der deut. geol. Gesell.*, 49, pp. 51–142, 1897.

magma" been injected and congealed *in situ,* we should expect to find evidence similar to that found in dike rocks. Doubly terminated quartz and cassiterite crystals (early minerals) freely suspended in a matrix of other crystals, possibly intergrowths, are to be looked for. These textures are notably absent. Instead, such features as banded and comb-structure, replacements of both ore minerals and country rock, quartz deposited as a gel, and extensive open spaces containing well-crystallized minerals, are present, features which are inconsistent with the known or supposed behavior of either natural or "ore" magmas. Indeed, these facts find ready explanation on no other basis than that of deposition by mobile solutions, in part filling the openings along fissures or between a rubble of rock fragments.

Granting that circulating solutions were the media responsible for deposition, it remains to offer a rational explanation for the outstanding feature of often-repeated cycles of similar mineralization in the various bands.

The occurrence of the vein in a Tertiary rhyolite flow whose original surface could not have been much higher than the present,[5] and the presence of quartz originally deposited as a gel, are indications of its near-surface origin at moderate temperatures. Where the ore is deposited about country rock fragments the continuously interlocking nature of the bands and the positions of the remaining, sometimes highly replaced and relic, cores indicate that the fragments were originally in contact and may, therefore, be reasonably interpreted as fault breccia.

The generalized sequence of deposition seems, from mineragraphic study, to have been: Pyrite—earliest; arsenopyrite; quartz and cassiterite; chalcopyrite; stannite; sphalerite; galena; tetrahedrite; silver and matildite; jamesonite and late quartz.

It will be noted that the sequence agrees closely with that given by Davy.[6] Chalcopyrite and stannite appear here in reversed relation, however.

[5] Lindgren, W.: Personal communication.

[6] Davy, W. Myron; "Ore Deposition in the Bolivian Tin-silver Deposits," ECON. GEOL., vol. 15, p. 491, 1920.

It is interesting to note that the early position of the fine-grained cassiterite makes it an undoubted primary mineral.

Arsenopyrite, while a mineral of somewhat persistant tendencies, is most characteristically associated with deposits formed at the higher temperatures. This, when present, assumes a very early position in the bands together with the simple minerals quartz and pyrite. The more complicated tetrahedrite, matildite, and jamesonite are late minerals. In keeping with the generalization that, other things being equal, chemistry at higher temperatures favors the formation of simpler compounds than at low temperatures, this relation seems to indicate a decrease in temperature of the depositing solutions. According to this view, solutions, repeatedly refreshed, entered the fissure at intermediate temperatures and, due to close proximity to the surface, were rapidly cooled, depositing, upon previously formed minerals, other minerals characteristic of the changing conditions. The pressure, being essentially hydrostatic, was not a controlling factor in the changing conditions, and its small magnitude urged no extensive replacement, favoring, rather, open space deposition. Quartz, delicately banded and well crystallized, although often of almost chalcedonic appearance, represents the final stages of magmatic emanations, covering all free surfaces.

The variation in the nature of the ores of different sections of the vein is a difference more of degree than of kind. The Oploca ore contains a little stannite, so characteristic of the Las Animas ore, while the latter contains, in early bands, pyrite, quartz, and cassiterite, which form the bulk of the Oploca minerals. The higher temperature indications of the Oploca ore may be assigned to a lateral component of migration of the depositing solutions, which would favor the deposition of the least soluble, high temperature, minerals at the Oploca section of the vein, while the lower temperature minerals would be deposited almost exclusively in the cooler Las Animas portion.

SUMMARY.

A few general observations may be made in summarizing the mineralization indicated by the suite. The vein occurs in a fault fissure in a rhyolite flow; it contains large quantities of two commonly persistent minerals, pyrite and quartz. The latter is here sometimes of colloidal origin. Tourmaline and topaz are entirely absent. Banded structure and small vugs are the rule. The mineralization of any one part of the vein appears to remain essentially constant throughout the entire period of deposition, but between different sections of the vein there is a variance in the nature of the ores. Cassiterite always appears closely associated with quartz, although the converse is not necessarily true. The last stage of the minerogenetic period is, in general, quartz, forming distinctly crystalline crusts on all free surfaces.

The evidence points to the formation of the deposit by deposition from mobile solutions. The occurrence of similar mineralogical character in later bands is interpreted as meaning that fresh solutions had entered and, on cooling, deposited minerals characteristic of the changing conditions. The type of mineralization contrasts strongly with that of the hypothermal, replacement tourmaline deposits of Caracoles, described recently by Lindgren.[7]

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[7] Lindgren, W.: "Replacement in the Tin-bearing Veins of Caracoles, Bolivia," ECON. GEOL., vol. 21, pp. 135–144, 1926.

SEPARATION OF FOSSILS AND OTHER LIGHT MATERIALS BY MEANS OF HEAVY LIQUIDS.[1]

MARCUS A. HANNA.

For the past few years, both in petrographic and biologic sedimentary analyses, the writer has used extensively gravitative separations through the use of liquids of various specific gravities. Most of this technique was recently well described in a paper in this journal by C. S. Ross.[2] There are, however, a few uses to which liquids of various specific gravities can be put, which were not mentioned. Since these are extremely valuable in sedimentary correlative work in connection with petroleum geology, both from the standpoint of time and completeness of separation, a few brief statements will be given here to be used as a guide. These can be elaborated upon as conditions demand. As the writer's work in this branch of sedimentary analyses has been confined chiefly to post-Paleozoic formations, the uses mentioned pertain largely to the analyses of the softer deposits.

Since the technique involved in heavy mineral separation has been adequately described by Ross and others, no mention of it will be made here; and as the principles involved in the separation of other "light materials" are similar, only the separation of fossils and glauconite will be pointed out here.

The writer has found that the first essential in sedimentary analyses is the standardization of samples. Several methods are in use, which have varying degrees of accuracy. The writer employs the following for general use:

1. Freeing the sample from contaminating material, drill mud, etc. Where this is not possible the necessary notes are recorded.

[1] Published with permission of the Gulf Production Company.

[2] Ross, C. S., "Preparation of Sedimentary Materials for Study," ECON. GEOL., vol. XXI, no. 5, August 1926, pp. 454–468.

2. Complete drying at a temperature of about 150 degrees centigrade to break down colloids and facilitate washings. Complete drying is very essential in washing "gumbo."
3. Weight.
4. Soaking in water, boiling, NaOH, etc., as required.
5. Washing with a stream of water on a 200-mesh sieve.
6. Washing into a filter paper and drying at about 100 degrees centigrade.
7. Weight.

This gives uniform standardization, and a percentage unit, ie. the percentage of material passing through a 200-mesh sieve. Screening for size percentage, and other mechanical analyses are made after washing. Heavy materials are then taken with the customary liquids.

When one does not need heavy mineral analyses, but desires both speed in work and efficiency in separation of fossils, bromoform is the chief liquid required. The gravity of bromoform can vary from 2.90, which is chemically pure, to the gravity of the liquid being used for dilution. Benzol has a gravity of slightly more than .878. The usual commercial bromoform has a specific gravity of about 2.60. By washing the commercial product in water and filtering, as was discussed by Ross[3] the specific gravity can be increased toward 2.90. Starting with a bromoform-benzol liquid of at least 2.68 specific gravity, any lesser gravity can be obtained by dilution with benzol. The gravity of the resulting liquid can be determined rapidly by several methods. The following are mentioned:

1. By weight.
2. With a Hydrometer.
3. By the floating or sinking of minerals of known specific gravity, *i.e.*, a chunk of calcite, quartz, orthoclase, etc.

Where no great detail is required the first desirable separation is with a liquid having a specific gravity less than calcite (2.715), but greater than quartz (2.66). In this liquid quartz will float,

[3] Ross, C. S., *op. cit.*, pp. 457–58.

but everything of greater gravity than the liquid will sink. The heavy separate will contain almost all the calcite and aragonite fossils which do not have air filled cavities, as well as pyritic pseudomorphs, etc. The minerals commonly known as " heavy " will also be separated. Such a separation is very valuable where fossils are few in a sand.

The material which floated in the first separation is again separated, this time in a liquid having a specific gravity less than quartz (2.66). A satisfactory specific gravity for the liquid, where orthoclase (2.56) is not too abundant, is between 2.66–2.56. Nearly all of the quartz will be taken out. The light separate will contain nearly all the glauconite (2.8–2.2), and those fossils in which there are air filled cavities, ie. double valves of ostracods and pelecypods, foraminifera, etc. Other light materials will also be present. By these two cuts ninety percent or more of the fossils can be separated from the quartz sand in a few moments. Where fossils are abundant such separations are not necessary, but with 250 cc. of quartz sand which contains 10 foraminifera, the time saved can be counted in hours.

Where glauconite is abundant, it can be separated from most of the " air-cavity " fossils by a bromoform-benzol liquid with a specific gravity of 2.20. Some of the glauconite filled shells will sink with the glauconite, but the percentage of perfect foraminifera etc. recovered makes the separation well worth while.

The results will be approximately as follows:

" Air-cavity " fossils, etc.
2.20 sp.gr. bromoform.
Glauconite, orthoclase, glauconite filled shells, etc.
2.60 sp.gr. bromoform.
Chiefly quartz.
2.685 sp.gr. bromoform.
Calcite, and aragonite fossils, and heavy minerals.

Any degree of preciseness desired can be obtained through the use of liquids of various specific gravities. The writer uses greater detail than the above would indicate, because more data are desired than are given by fossils. However, for rapid, ac-

curate results where fossils only are involved, the above will suffice. In sparsely fossiliferous sands, the percentage of separation, and the time saved is astounding.

Caution.—Bromoform and benzol should not be used in an open room. They should be used only in a well ventilated hood. The vapors from both are poisonous, and more or less accumulative in their effect. However, with proper ventilation and complete washing of the separates with alcohol and ether before drying, safety is obtained.

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THE HYDROTHERMAL ALTERATION OF CERTAIN SILICATE MINERALS.

R. J. LEONARD.

INTRODUCTION.

THE object of this paper is to place on record the results of an experimental study undertaken to show the conditions for formation of certain alteration products of silicate minerals. It is commonly known that natural reactions change anhydrous silicates to hydrous silicates and other products, but the solutions which bring about such changes are not well known. It was with the intention of testing the effects of certain solutions that this investigation was begun.

Experimental work of this nature done by earlier investigators has usually given negative results,—failed to produce any of the common alteration products found in mineral deposits and mineralized zones. In many ore deposits and the regions immediately surrounding them chemical alterations and replacements have occurred, both accompanying and following ore deposition, and the feldspars, particularly, have been greatly affected. It is generally thought that this alteration effect has been brought about by the same solutions that deposited the ore minerals. Any data relative to solutions, temperatures and pressures used to effect such alteration artificially might well be of value, both from the standpoint of ore genesis and that of interpretation of the geologic history of such occurrences.

Of the various alteration products derived from the feldspars by processes related to ore deposition, the chief ones, both in abundance and in significance, are probably sericite, kaolinite, and alunite. The factors responsible for these transformations of the varied feldspars are largely matters of speculation and the hypotheses advocated in particular cases are based on field conditions.

Sericite ($K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$) is considered one of the most abundant and characteristic of hydrothermal minerals. In association with ore deposits it is generally held to be a product of reaction between the feldspars and the ascending hot solutions which deposit the primary minerals. As pointed out by Emmons,[1] there is little evidence indicating that it forms extensively under the conditions prevailing where secondary sulphides are deposited. The reaction resulting in the formation of sericite from anhydrous silicates has been recently discussed by Goldschmidt[2] and by Boydell.[3]

Sericitization is considered by many geologists to be an intermediate stage in the process of kaolinization. As for the origin of kaolin or kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), various views have been maintained[4] but the commonly accepted one holds that it is a residual product from weathering of feldspars.

Alunite ($K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$) is abundant and widely distributed in altered volcanic rocks. It occurs also as a secondary (supergene) mineral in the oxidized zone of ore deposits.[5] It was once considered only a product of reaction between feldspathic rocks and sulphurous fumarolic vapors. In late years, however, several hypotheses have been developed, each of which satisfactorily explains certain occurrences of the mineral. The alunite deposits near Marysvale, Utah,[6] are of special interest, since they occur as vein fillings of unusual size and notably free from impurities, as well as a wall-rock alteration product. Here, for the vein filling, the mineral content was undoubtedly introduced by

[1] Emmons, W. H., "Enrichment of Ore Deposits," U. S. Geol. Survey Bull. 625, p. 480, 1917.

[2] Goldschmidt, V. M., "On the Metasomatic Processes in Silicate Rocks," ECON. GEOLOGY, vol. 17, p. 116, 1922.

[3] Boydell, H. C., "A Discussion on Metasomatism and the Linear Force of Growing Crystals," ECON. GEOL., vol. 21, p. 38, 1926.

[4] See Clarke, W. F., "The Data of Geochemistry," U. S. Geol. Survey Bull. 770, p. 494, 1925; also Emmons, W. H., *op. cit.*, p. 478; and the articles therein referred to.

[5] Butler, B. S., "Primary (Hypogene) Sulphate Minerals in Ore Deposits," ECON. GEOL., vol. 14, p. 586, 1919.

[6] Butler, B. S., and Gale, H. S., "Alunite, a Newly Discovered Deposit near Marysvale, Utah," U. S. Geol. Survey Bull. 511, 1912.

solutions of deep-seated origin.[7] Loughlin,[8] in a later report, essentially agrees with these findings. Alunitic deposits in Colorado[9] and British Columbia[10] are thought to have been formed by ascending hot acid solutions of deep-seated origin. The alunite of Goldfield, Nevada,[11] is worthy of special note in that it is so abundant in the ore bodies and so widely disseminated and generally associated with the intense alteration of the surrounding rocks that it is considered one of the characteristic minerals of the gold deposits. Ransome fully discusses[12] the different methods of possible formation and concludes that a process combining solfatarism and oxidation best explains this particular occurrence. Lindgren[13] and others have described occurrences.

The field evidence clearly shows the lack of definite knowledge concerning the character of solution forming these different alteration products. It is not known whether the solutions are hot or cold, ascending or descending, acid or alkaline, under pressure or not, or whether such conditions are variable and not the most important factors involved.

PREVIOUS WORK.

For many years various research workers have devoted more or less experimental study to this subject of hydrothermal alteration and synthesis of silicate minerals. Doelter's Mineralchemie[14] contains references to most of the published work of this nature. In an article reviewing the work done on the hydrothermal forma-

7 Butler, B. S., and Gale, H. S., *Idem*, p. 36.

8 Loughlin, G. F., "Recent Alunite Developments near Marysvale and Beaver, Utah," U. S. Geol. Survey Bull. 620, p. 237, 1915.

9 Larsen, E. S., "Alunite in the San Cristobal Quadrangle, Colorado," U. S. Geol. Survey Bull. 530, p. 183, 1913.

10 Clapp, C. H., "Alunite and Pyrophyllite in Triassic and Jurassic Volcanics at Kynquot Sound, British Columbia," ECON. GEOL., vol. 10, pp. 70–88, 1915.

11 Ransome, F. L., "The Geology and Ore Deposits of Goldfield, Nevada," U. S. Geol. Survey Prof. Paper 66, pp. 129–33, 1909.

12 Ransome, F. L., *Idem*, pp. 189–95.

13 Lindgren, W., "The Copper Deposits of the Clifton-Morenci District, Arizona," U. S. Geol. Survey Prof. Paper 43, pp. 119–20, 1905.

14 Doelter, C., "Handbuch der Mineralchemie," Band II, Teil 1, 1914; Teil 2, 1917; Teil 3, 1921.

tion of silicates Morey and Niggli [15] have chronologically arranged a complete, abstracted bibliography of the experimental data published up to and including the year 1912. During the years since 1912 but few papers dealing with this subject have been published and only one of these, that of Stephenson,[16] has to do with the formation of alteration products. In fact, in a large proportion of the investigations of this character recorded in the literature since the beginning of such experimental work the minerals obtained have been formed entirely from mixtures of their chemical constituents. Whether or not this method of attacking the problem is of great geologic value is a debatable question. It would seem that the hydrothermal formation of minerals as a result of the breaking down and alteration of natural silicates would have a greater geological significance and a far wider application, since, in the case of so many of them, it is apparent that they have generally so originated in nature.

Among the investigations dealing with replacement and transformation of minerals, those of Lemberg, spread over a number of years, supplied a remarkable volume of data; his experiments made with kaolin in aqueous salt solutions are probably the most important of his work.[17] Thugutt [18] likewise studied the alkali replacement and the transformation of kaolin, repeating some of Lemberg's experiments. The Friedels [19] dealt with the alteration of muscovite. Königsberger and Müller [20] worked with various minerals and rocks. Experiments by Friedel and Grandjean [21]

[15] Morey, G. W., and Niggli, P., "The Hydrothermal Formation of Silicates," *J. Am. Chem. Soc.*, vol. 35, pp. 1086–1130, 1913.

[16] Stephenson, E. A., "Studies in Hydrothermal Alteration," *Jour. Geology*, vol. 24, pp. 180–99, 1916.

[17] Lemberg, J., *Z. deut. geol. Ges.*, vol. 28, pp. 519–621, 1876; vol. 35, pp. 557–618, 1883; vol. 39, pp. 559–600, 1887.

[18] Thugutt, St. J., *Z. anorg. Chem.*, vol. 2, pp. 64–107, 113–156, 1891; *N. Jahrb. Min. Geol.*, Beil. Bd. 9, pp. 554–624, 1894.

[19] Friedel, C. and G., *Compt. rend.*, vol. 110, pp. 1170–78, 1890; *Bull. soc. min.*, vol. 13, pp. 129–39, 182–87, 238–41, 1890, vol. 14, pp. 69–75, 1891, vol. 19, pp. 5–14, 1896, vol. 24, pp. 141–59, 1901.

[20] Königsberger, J., and Müller, W. J., *Centralbl. Min.*, 1906, pp. 339–48, 353–72.

[21] Friedel and Grandjean, *Bull. soc. min.*, vol. 32, pp. 150–54, 1909.

dealt with augite and diopside. Stephenson [22] experimented with feldspars and hornblende in alkaline solutions. Of the purely synthetic experimental studies, those of Chroustschoff,[23] dealing with colloidal mixtures, and those of Baur,[24] dealing with various oxides, furnish much suggestive data.

While some eighty known minerals are reported to have been produced by hydrothermal experiments,[25] only thirty of these can be listed as resulting from the alteration of other minerals. The following list gives the minerals thus produced, with the number of investigations in which produced in parenthesis after each:

Quartz (2)
Tridymite (1)
Chalcedony (1)
Opal (1)
Spinel (1)
Calcite (1)
Dawsonite (?1)
Orthoclase (3)
Anorthoclase (1)
Albite (1)
Leucite (4)
Aegerine-augite (1)
Pectolite (2)
Hornblende (1)
Nephelite (3)
Hydrous Na-nephelite (2)
Cancrinite (1)
Na-cancrinite (3)
Sodalite (1)
Nosean (1)
Phenacite (1)
Analcite (6) (?1)
Natrolite (1) (?3)
K-natrolite (1)
Scolecite (?2)
Mesolite (?1)
Muscovite (?1)
Biotite (?1)
Chlorite (1)

Sericite, here considered a distinctive mineral and not a variety of muscovite, has never been reported as an experimental product, though Doelter,[26] Baur,[27] and Thugutt [28] produced muscovite and

[22] Stephenson, E. A., *op. cit.*

[23] Chroustschoff, K. von, *Compt. rend.*, vol. 104, pp. 602–3, 1887, vol. 112, pp. 677–79, 1890; *N. Jahrb. Min. Geol.*, vol. 2, pp. 86–90, 1891.

[24] Baur, Emil., *Z. physik. Chem.*, vol. 42, pp. 567–76, 1902; *Z. anorg. Chem.*, vol. 72, pp. 119–61, 1911.

[25] See Morey, G. W., and Niggli, P., *op. cit.*, Tabular Summary, pp. 1128–30.

[26] Doelter, C., *Tsch. Min. und Pet. Mit.*, vol. 10, pp. 76–88, 1888–89; "Handbuch der Mineralchemie," Band II., Teil 2, p. 438, 1917.

[27] Baur, E., *Z. anorg. Chem.*, vol. 72, pp. 119–61, 1911; *Z. Elektrochem.*, vol. 17, pp. 739–42, 1912.

[28] Thugutt, St. J., *N. Jahrb. Min. Geol.*, Beil. Bd. 9, pp. 554–624, 1894.

" potash mica "; Doelter by fusion at low red heat, Baur by hydrothermal synthesis, and Thugutt by hydrothermal alteration of elaeolite.

Kaolin has been produced by but one investigator, Collins,[29] by treating feldspars and granite with hydrofluoric acid, according to the ideas of von Buch and Daubrée, who, from observations of kaolin in association with fluorine-containing minerals, believed that certain kaolin occurrences owed their origin to this acid.[30]

Alunite as an experimental product has never been definitely reported, although Sainte-Claire Deville is given credit by Ransome [31] for having produced the mineral artificially. However, it is questionable whether or not Deville's experiment [32] definitely produced alunite.

PLAN OF THE WORK.

The experimental work to be described in the following pages was undertaken for the general purpose of studying the effect of different solutions at various temperatures and pressures upon certain feldspars (and spodumene), but with the specific objective the production of one or more of the alteration products: sericite, kaolinite, alunite.

In the matter of ultimate determination of the treated mineral powders a distinct advantage is here gained over the work of earlier investigators in that by means of the recently developed X-ray method for studying crystalline materials in powdered form any crystalline products obtained can be definitely identified. The available methods of identification before the perfection of this X-ray powder method frequently fell short of definite determination. The X-ray " Powder " method—more properly the " Hull-Debye-Scherrer " method—of crystal analysis has now become sufficiently well known not to require detailed explanatory discussion here. The method is fully described and illustrated by

[29] Collins, J. H., " On the Nature and Origin of Clays; the Composition of Kaolinite," *Mineralogical Mag.*, vol. 7, pp. 205–14, 1887.

[30] *Idem*, p. 212.

[31] Ransome, F. L., *op. cit.*, p. 195.

[32] Deville, Ch. St.-C., " Sur la presence de la leverrierite dans les tonsteins du houllier de la Saare," *Compt. rend.*, vol. 35, pp. 261–64, 1852.

Hull,[33] and more recently Kerr [34] has given a detailed discussion of the theory, method, apparatus, technique, and also a considerable number of patterns. Davey [35] has very recently described the method and discussed matters of improved technique and interpretation of patterns. The fact has been well established that every crystalline substance has a definite pattern, different from those of all other substances (excepting in cases of isomorphism, where the differences are usually small, sometimes much too small to be noted), and in a mixture of substances each produces its pattern independently of the others, but the number of substances thus determinable in a mixture is necessarily limited by the number of lines produced in the pattern, for a confusion of lines makes interpretation difficult and uncertain; this also applies quantitatively to the intensity of the lines.

The minerals used in this investigation have been reasonably free from impurities. All were powdered to pass a 200-mesh sieve. Excepting labradorite, the composition of which was checked by refractive indices, all were previously analyzed. The microcline, albite and spodumene were from the Etta mine, Black Hills, South Dakota; the bytownite from near Beaver Bay, north shore of Lake Superior, Minnesota; the labradorite from locality unknown.

In all but the IX. and X. groups of experiments the reactions were carried on in Pyrex glass. It is held by some investigators that glass containers may be an important source of error and should therefore be avoided when possible, but it is contended here that natural conditions are being more nearly followed by using a silicate rather than a metallic container. Blank experiments for check were made and did not give any evidence of the glass being an essential factor in the production of the alteration substances obtained; blank checks are discussed in Group VI.

[33] Hull, A. W., "A New Method of Chemical Analysis," *J. Am. Chem. Soc.*, vol. 41, pp. 1168–75, 1919.

[34] Kerr, P. F., "The Determination of Opaque Ore-Minerals by X-ray Diffraction Patterns," ECON. GEOL., vol. 19, pp. 1–34, 1924.

[35] Davey, W. P., "A Study of Crystal Structure and its Applications," Part VI., *General Elec. Rev.*, vol. 28, pp. 586–99, 1925.

The experimental work extended over a period of 14 months but the results can be presented in full detail in a series of short tables. The experiments were conducted in group series, under varying group conditions of temperature, pressure, state of chemical reagents, concentration and volume of solutions, duration, style of apparatus, etc., as indicated in the headings of the following group tabulations, which briefly give the result obtained in each experiment. The treated products were boiled three to four times in small amounts of distilled water and washed with hot water in order to remove all soluble salts. In studying and identifying the substances recovered in each experiment the usual methods were employed—microscopic, principally for refractive index, blowpipe tests when feasible, partial and complete quantitative chemical analysis—as well as the X-ray method. Further explanation and discussion relative to the experiments of any given group accompany the tabulations for that group.

EXPERIMENTAL WORK.

Group I.—These experiments were conducted in a two-liter Pyrex flask containing one liter of 0.05 molar solution, one gram of mineral powder and a fragment of the same mineral. Every 24 hours 250 c.c. of the solution were siphoned off and as much new solution added. The flask was fitted with a cork stopper and a condenser and placed on an electric hot-plate, where the temperature of the solution was maintained at a slow boil.

TABLE I.

Temperature: 100° C. Time: 14 days.

4 Liters 0.05 *M* Solution.	Mineral (1 gm., 200-mesh).				
	Microcline.	Albite.	Labradorite.	Bytownite.	Spodumene.
K_2CO_3	No change	No change	No change	No change	No change
Na_2CO_3	" "	" "	" "	" "	" "
KCl	" "	" "	" "	" "	" "
NaCl	" "	" "	" "	" "	" "
HCl	" "	" "	10% Silica		
K_2SO_4	" "	Corrosion		Corrosion	" "
Na_2SO_4	" "	"		"	" "
H_2SO_4	" "	No change	90% Silica	80% Silica	" "

The above results, excepting those obtained in the treatment of labradorite and bytownite with sulphuric acid and labradorite with hydrochloric acid, are significant only in a negative manner so far as actual alteration products are concerned. The potassium and sodium sulphate solutions produced a slightly corroded appearance in some grains of albite and bytownite, as seen microscopically. Labradorite was in part decomposed by hydrochloric acid, some silica skeletons being noted under the microscope.

The outstanding result of this group of experiments is the product obtained in the reactions of sulphuric acid on labradorite and bytownite; these two silicates being almost completely decomposed and only hydrous silica remaining as an alteration or decomposition product. The x-ray film for the altered bytownite product was blank—denoting an amorphous substance (the labradorite product was not photographed). Chemical analyses of the original bytownite and the alteration products from bytownite and labradorite in the sulphuric acid experiments are as follows:

	Bytownite.		Labradorite.
	Fresh.	About 80% Altered.	About 90% Altered.
SiO_2	47.97	79.70	81.05
Al_2O_3	33.07	7.45	3.55
CaO	15.57	0.84	0.21
MgO	0.16		
Na_2O	3.00	n.d.	n.d.
K_2O	0.53		
Ignition	0.38	12.50	15.60
	100.68	100.49	100.41

Group II.—In this group of experiments 500 c.c., 0.05 molar solutions, of sulphuric acid, of potassium sulphate, of sodium sulphate and of aluminum sulphate were used, to each of the first three of which 50 grams of aluminum sulphate were added. A one-liter Pyrex flask was used; the flask was fitted with a cork stopper and a condenser and placed on an electric hot-plate, where the temperature of solution was maintained at a slow boil; the solution was not renewed.

TABLE II.*

Temperature: 100° C. Time: 7 days.

500 c.c. Solution.	Mineral (1 gm., 200-mesh).			Blank.
	Microcline.	Albite.	Bytownite.	
$H_2SO_4 + Al_2(SO_4)_3$.....	2.12 gm.* 20% Silica 60% Alunite	1.42 gm. 80% Alunite	1.90 gm. 40% Silica 60% Alunite	
$K_2SO_4 + Al_2(SO_4)_3$.....	7.35 gm. 95% Alunite	13.65 gm. 95% Alunite	2.43 gm. 10% Silica 85% Alunite	12.55 gm. Alunite
$Na_2SO_4 + Al_2(SO_4)_3$.....	8.97 gm. 95% Alunite	9.25 gm. 95% Alunite	10.95 gm. 99% Alunite	9.72 gm. Alunite
$Al_2(SO_4)_3$.....	1.50 gm. 50% Alunite	1.17 gm. 50% Alunite	1.30 gm. 60% Alunite	

**Note:* In this and the following tabulations the weight of the resulting product for each experiment will be stated, and under it the percentage of new product as estimated under the microscope. Any balance needed to total 100 per cent. is to be understood as the residue of original mineral. In some cases at least, the estimated percentage of alunite probably includes hydrous silica or other substance which may have been overlooked in the microscopic examination because of the finely divided state of the product. Also, concerning alunite, the new mineral product is designated "alunite," whether or not it may be the pure potassium variety, an isomorphous mixture of potassium and sodium, or the soda variety, natroalunite.[36]

The fact that alumina was in great part removed in the treatment of bytownite and labradorite with sulphuric acid in Group I. and only hydrous silica remained, suggested that if an experiment was made in which an aluminum compound was added to the sulphuric acid solution until a condition of equilibrium between the two was approached, then the alumina of the mineral might be retained, together with the hydrous silica, and kaolinit might be produced. That the reaction did not so result is evident from the above series of experiments. While in most cases the silicate mineral was not entirely decomposed, all that remained showed evidence, microscopically, of partial alteration. The product obtained varied from extremely finely divided material to a rather

[36] Hillebrand, W. F. and Penfield, S. L., "Some Additions to the Alunite-Jarosite Group of Minerals," *Am. J. Sci.*, vol. 14, p. 220, 1902; Dana's "System of Mineralogy," Appendix II., p. 73.

coarse gritty powder, and the color from flat-white to flesh-colored. Microscopic determinations, principally of refractive index, and blowpipe chemical tests were made in every case, analytical chemical determinations and x-ray diffraction patterns from the products in four of the above experiments. That alunite or a variety of alunite had been formed was indicated in all tests and definitely evident from the x-ray patterns—shown in part in Figure 1.

Since it required the addition of aluminum sulphate to the alkali sulphate and sulphuric acid solutions of Group I. to pro-

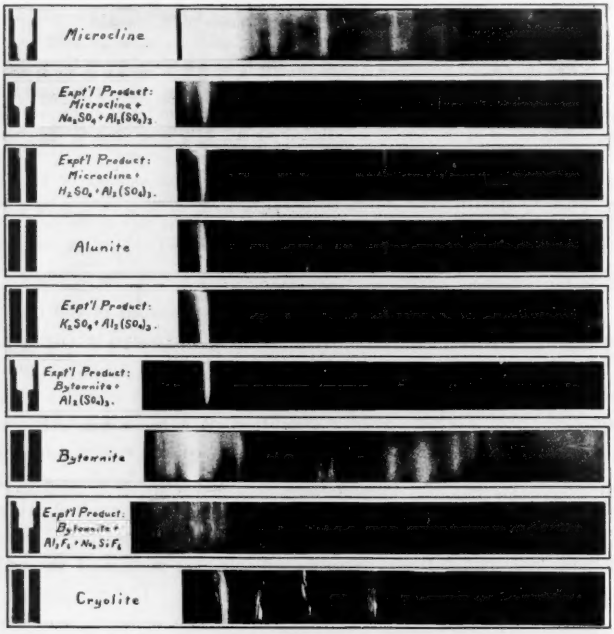

FIG. 1. Positive Prints of Diffraction Patterns. Note: The experimental-product patterns shown represent all of the alunite and cryolite patterns obtained from various experiments at different temperatures.

duce the alunite, and since aluminum sulphate solution alone can also effect its production, it would appear that aluminum sulphate is the necessary factor required under the above conditions to bring about this particular alteration.

That alunite may be formed purely synthetically from a mixture of aluminum sulphate and alkali sulphate solutions is also evident, as shown by the "blank" experiments tabulated above and also indicated in certain of the others, where the weight of product is large. A diffraction pattern is shown in Figure 1.

Group III.—In this group all conditions of solution and mineral, excepting temperature and time, were as in the preceding group. The experiments were conducted in 500 c.c. Pyrex flasks with watch-glass covers, were placed on a steam-bath, and were occasionally shaken.

TABLE III.

Temperature: 65° C. Time: 60 days.

500 c.c. Solution.	Mineral (1 gm., 200-mesh).			Blank.
	Microcline.	Albite.	Bytownite.	
$H_2SO_4 + Al_2(SO_4)_3$.....	1.18 gm.	1.17 gm.	0.80 gm.	
	50% Alunite	60% Alunite	39% Silica 60% Alunite	
$K_2SO_4 + Al_2(SO_4)_3$.....	6.77 gm.	6.60 gm.	10.32 gm.	5.24 gm.
	85% Alunite	90% Alunite	9% Silica 90% Alunite	Alunite
$Na_2SO_4 + Al_2(SO_4)_3$.....	4.43 gm.	5.03 gm.	6.92 gm.	1.35 gm.
	90% Alunite	90% Alunite	9% Silica 90% Alunite	Alunite
$Al_2(SO_4)_3$.....	1.46 gm.	1.59 gm.	1.89 gm.	
	80% Alunite	80% Alunite	19% Silica 80% Alunite	

Group IV.—All conditions as in Group III., excepting that the flasks were fitted with rubber stoppers and placed on a laboratory table.

It was desired to know if alunite could be produced at lower temperatures than 100° C. The products obtained in Group III. and Group IV. were similar in every way to those of Group II. (100° C.), as were also x-ray patterns.

TABLE IV.

Temperature: 22° ± 2° C. Time: 60 days.

500 c.c. Solution.	Mineral (1 gm., 200-mesh).			Blank.
	Microcline.	Albite.	Bytownite.	
$H_2SO_4 + Al_2(SO_4)_3$	1.12 gm. 50% Alunite	1.11 gm. 50% Alunite	0.84 gm. 50% Alunite	
$K_2SO_4 + Al_2(SO_4)_3$	1.39 gm. 50% Alunite	1.39 gm. 60% Alunite	1.37 gm. 60% Alunite	0.49 gm. Alunite
$Na_2SO_4 + Al_2(SO_4)_3$	1.28 gm. 40% Alunite	1.27 gm. 40% Alunite	1.29 gm. 50% Alunite	0.33 gm. Alunite
$Al_2(SO_4)_3$	1.30 gm. 60% Alunite	1.42 gm. 60% Alunite	1.31 gm. 60% Alunite	

Group V.—These experiments were conducted in sealed Pyrex tubes of approximately 60 c.c. volume (inside dimensions about 1.3 cm. diameter by 43 cm. length) and heated in a Carius oven at 200° ± 5° C. for 7 days. A maximum pressure of about 15 atmospheres was developed. Here 15 c.c. of 0.1 molar solutions of sulphuric acid, of potassium sulphate and of sodium sulphate were used, to each of which 3 grams of aluminum sulphate were added; also a molar solution of aluminum sulphate was used, but with 0.5 gram of mineral instead of 1.0 gram.

TABLE V.

Temperature: 200° C. Pressure: 15 atm. Time: 7 days.

50 c.c. Solution.	Mineral (1 gm., 200-mesh).		
	Microcline.	Albite.	Bytownite.
$H_2SO_4 + Al_2(SO_4)_3$	1.75 gm. 25% Silica 60% Alunite		1.65 gm. 30% Silica 70% Alunite
$K_2SO_4 + Al_2(SO_4)_3$	2.18 gm. 70% Alunite	2.60 gm. 80% Alunite	2.90 gm. 10% Silica 90% Alunite
$Na_2SO_4 + Al_2(SO_4)_3$	2.20 gm. 60% Alunite	2.10 gm. 60% Alunite	2.62 gm. 9% Silica 90% Alunite
$Al_2(SO_4)_3$	1.18 gm. 90% Alunite		1.16 gm. 10% Silica 90% Alunite

It was also deemed advisable to know if alunite would be produced at a temperature higher than 100° C. With the exception of a variation in the weight of new product the experiments resulted quite similarly to those of Groups II., III. and IV. X-ray patterns are shown in Figure 1.

Analyses of specimen of alunite from Tolfa, Italy, from which the x-ray diffraction pattern for comparison was made, and of the products from two experiments in which alunite was formed, also of the two feldspars involved, are as follows:

	Microcline from Etta Mine, S. Dakota.	Product from Microcline H_2SO_4 $Al_2(SO_4)_3$ Experiment 200° C.	Alunite from Tolfa, Italy.	Product from Bytownite $Al_2(SO_4)_3$ Experiment 65° C.	Bytownite from Beaver Bay, Minnesota.
SiO_2	63.79	24.33	—	21.89	47.97
Al_2O_3	20.35	27.03	37.26	31.39	33.07
CaO	.25	—	—	—	15.57
MgO	.38	—	—	—	.16
Na_2O	2.39	3.02	3.04	7.84	2.70
K_2O	12.55	7.17	8.71		.54
SO_3	—	22.24	38.54	28.62	—
H_2O	.24	16.21*	12.45*	10.26*	.38
	99.95	100.00	100.00	100.00	100.39

* Estimated.

MINERAL CALCULATION.

Product from Microcline $H_2SO_4 + Al_2(SO_4)_3$ (200° C. Expt.).	Total Wt. in Grams.	SiO_2.	Al_2O_3.	Na_2O K_2O.	SO_3.	H_2O.
Weight in grams	1.7500	.4258	.4730	.1783	.4067	.2662
(20%) Microcline	.3500	.2240	.0734	.0526		
	1.4000	.2018	.3996	.1257		
(19%) $SiO_2 + H_2O$	.3280	.2018				.1262
	1.0720					.1400
(61%) Alunite	1.0720		.3966	.1222	.4138	.1394

Or in place of allotting the balance of product to alunite, as computed from the theoretical formula, it may be expressed in percentage composition and compared with the theoretical composition of alunite, as follows:

	Experimental.	Theoretical.
SO_3	37.94	38.60
Al_2O_3	37.27	37.00
Na_2O and K_2O	11.73	11.40
H_2O	13.06	13.00
	100.00%	100.00%

Group VI.—As in the preceding group, these experiments were conducted in sealed Pyrex tubes of approximately 60 c.c. volume and heated in a Carius oven at 200° C. for 7 days, with a maximum pressure of about 15 atmospheres being developed. Molar solutions and 0.2 gram mineral portions were used.

TABLE VI.

Temperature: 200° C. Pressure: 15 atm. Time: 7 days.

25 c.c. Solution.	Mineral (0.2 gm., 200-mesh).			
	Microcline.	Albite.	Labradorite.	Spodumene.
K_2CO_3		Phillipsite?	Phillipsite?	Phillipsite?
$KHCO_3$		No change		
Na_2CO_3	Thomsonite?			Mordenite?
$NaHCO_3$	Slight Corrosion	Much Corrosion		
KCl			No change	
NaCl	No change			
HCl	Dissolved			
H_2SO_4	0.11 gm. 60% Silica	40% dissolved, bal. corroded	0.09 gm. 99% Silica	60% dissolved
K_2SO_4		No change		
Na_2SO_4	No change			

In these experiments two varieties of positive results were obtained—the alkali carbonate reactions in which zeolites were formed, and acid reactions resulting in partial or complete solution of the minerals or decomposition with a residual silica product. As was expected, the alkali carbonate solutions attacked the glass of the tubes, forming a thin coating of hydrous silica, especially along the bottom half from end to end, which adhered more or less firmly to the glass and so involving the residual mineral powder and alteration product that they could be neither cleanly nor completely recovered. The zeolites were always formed in small botryoidal masses attached to the concave sur-

faces of the thicker strips of precipitate or substance along the bottom half of the tubes. Blank carbonate experiments resulted in hydrous silica and a same general appearance in the coating of the tubes as in those containing mineral. Bicarbonate blanks showed very little reaction with the glass, only a slight etching of the tube walls in spots and, in the potassium bicarbonate blank, a little fine, flaky silica was formed.

Group VII.—This group of experiments was made in sealed Pyrex tubes of approximately 50 c.c. volume. The mineral and dry reagent or reagents were thoroughly ground together in an agate mortar, placed in tube and about 0.1 gram (2 drops) water carefully added. The sealed tubes were heated in a Carius oven at 400° C. for 20 hours (two ten-hour periods), the temperature being recorded by means of a pyrometer. A maximum pressure of about 8 atmospheres was developed.

TABLE VII.

Temperature: 400° C. Pressure: 8 atm. Time: 20 hours.

Reagent (0.2 gm. of Each).	Mineral (0.2 gm., 200-mesh).			
	Microcline.	Albite.	Labradorite.	Bytownite.
$K_2F_2 + Al_2F_6$	0.24 gm. 30% Silica			
$K_2F_2 + Na_2SiF_6$	No change			
$Al_2F_6 + Na_2SiF_6$	0.45 gm. 90% Cryolite			
K_2CO_3	0.15 gm. Corroded		0.14 gm. Corroded	0.13 gm. 10% Silica. bal. corroded
Al_2F_6		0.36 gm. 60% Silica		
Na_2SiF_6		No change		

The production of a substance closely corresponding, microscopically, to cryolite is the particular feature of this group of experiments, although the corrosion and plainly indicated microscopic evidence of attack by potassium carbonate, especially in the reactions with labradorite and bytownite, has significance.

Group VIII.—The experiments of this group are but duplications of those of the preceding group, only with increased temperature and a correspondingly greater pressure.

TABLE VIII.

Temperature: 575° C. Pressure: 10 atm. Time: 20 hours.

Reagent (0.2 gm. of Each).	Mineral (0.2 gm., 200-mesh).			
	Microcline.	Albite.	Labradorite.	Bytownite.
$K_2F_2 + Al_2F_6$	0.59 gm. 80% Silica			
$K_2F_2 + Na_2SiF_6$	0.22 gm. 25% Leverrierite?			
$Al_2F_6 + Na_2SiF_6$	0.45 gm. 40% Silica 40% Cryolite			
K_2CO_3	0.16 gm. Etched and corroded		0.16 gm. 40% Leverrierite?	0.20 gm. 40% Leverrierite?
Al_2F_6		0.57 gm. 90% Silica		
Na_2SiF_6		0.47 gm. 90% Silica		

The temperature-pressure increase over that of the preceding group evidently caused radically different results to be effected in some cases. The new product obtained in the experiment: Microcline + K_2F_2 + Na_2SiF_6 occurs in fibrous bunches so closely resembling sericite as to be easily mistaken for it, but the index of refraction (between 1.508 and 1.529) excludes sericite and corresponds more nearly to the variable mineral, leverrierite.[37] And the products obtained in the potassium carbonate reactions with labradorite and bytownite similarly occur as fibrous bunches and as scattered fibres, with the same index of refraction but in part of a somewhat lower interference color. The reaction in the microcline-Al_2F_6-Na_2SiF_6 experiment produced, besides hydrous silica, a substance having a refractive index less than 1.40 but greater than 1.33 and otherwise closely corresponding to cryolite.

X-ray patterns of the products in which the leverrierite-like substance occurred proved unsatisfactory; apparently the alteration mineral product was not present in large enough quantities and was masked by the feldspar lines. A pattern of cryolite is shown in Fig. 1.

[37] See Corbett, C. S., "Leverrierite as a Schist-forming Mineral," *Am. J. Sci.*, vol. 10, pp. 247–68, 1925.

Group IX.—Superheated water vapor was brought in contact with the thoroughly mixed mineral powder and dry reagents contained in a small platinum crucible (15 c.c.). Steam was generated in a two-liter Pyrex flask, then conducted through a Pyrex tube of about one-eighth inch inside diameter by 18 inches length between bends and into a covered platinum crucible placed in a small absorption flask. The steam tube and absorption flask were wound with an electric heating element, the temperature of which was controlled by means of a rheostat. Asbestos paper was wrapped around the steam tube and element, also neck of large flask, and a removable asbestos "collar" placed around the absorption flask when the apparatus was in operation. A thermometer was so placed that its mercury bulb was in contact with the outside of the platinum crucible. See Fig. 2.

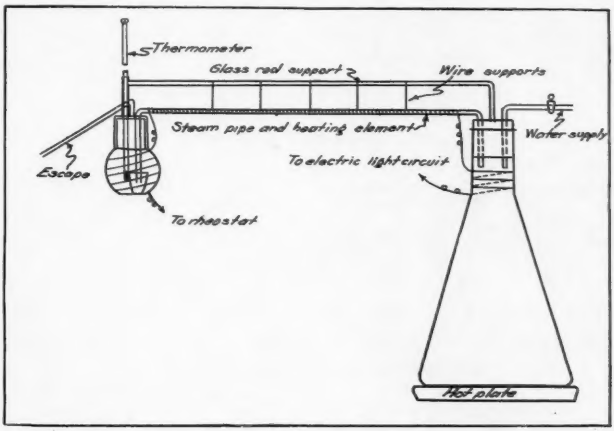

FIG. 2.

This group of experiments was suggested by Doelter's [38] work in the production of potash mica in fusion experiments, where the aluminum silicate, andalusite, and various fluorides were used,

[38] Doelter, C., *op. cit.*

and concerning which he states that an excess of aluminum silicate was necessary and that fluorides of all the elements involved were required in the mixture producing the mica.

TABLE IX.

Temperature: 350° C. Time: 9 hours.

Reagent (1 gm. of Each).	Mineral (0.5 gm., 200-mesh).		
	Microcline.	Albite.	Bytownite.
K_2F_2	No change		No change
Na_2F_2			No change
Al_2F_6		0.80 gm. 50% Silica	0.80 gm. 60% Silica
Na_2SiF_6	No change	0.42 gm. 10% Silica	
$K_2F_2 + Al_2F_6$	0.60 gm. 40% Phillipsite?	0.60 gm. 40% Phillipsite?	0.75 gm. 50% Phillipsite?
$K_2F_2 + Na_2SiF_6$	1.18 gm. 80% Silica		
$Al_2F_6 + Na_2SiF_6$	1.74 gm. 70% Silica 20% Cryolite	1.61 gm. 40% Silica 30% Cryolite	1.99 gm. 40% Silica 40% Cryolite
KCl		No change	
NaCl	No change		
$AlCl_3$	0.75 gm. 60% Leverrierite?	0.74 gm. 60% Leverrierite?	
$KCl + AlCl_3$		0.72 gm. 50% Leverrierite?	0.76 gm. 70% Leverrierite?
$NaCl + AlCl_3$	0.73 gm. 60% Leverrierite?	0.59 gm. 50% Leverrierite?	
$K_2SO_4 + Al_2(SO_4)_3$			No change
Na_2SO_4	No change		
Na_2CO_3	No change		

In the K_2F_2–Al_2F_6 experiments, producing what is believed to be phillipsite, satisfactory x-ray patterns were not obtained, since the feldspar lines predominate and the few additional lines are faint and uncertain. Optical determinations, however, strongly suggest phillipsite, especially so in the product derived from bytownite.

In the experiments in which cryolite was produced the reagents used, Al_2F_6 and Na_2SiF_6, in themselves contain the necessary constituents to form the mineral synthetically; such an experiment was made but no cryolite was produced, although it was easily obtained by fusion of these two reagents. X-ray patterns are shown in Figure 1.

The products obtained in the "chloride" series of experiments agree optically with leverrierite, according to Termier [39] and to the Colorado leverrierite reported by Larsen and Wherry.[40] It appears under the microscope as brownish to yellowish-green colored grains, faintly pleochroic, refractive index mostly 1.536–1.544 and increasing with continued immersion in oil. The x-ray patterns obtained show a confusion of faint lines, with feldspar lines predominating. The multiplicity of faint lines makes identification too uncertain, although another crystalline substance, in addition to the feldspar, is indicated.

Group X.—These experiments were conducted in the same apparatus as those of Group IX. A pyrometer was used for recording the temperature.

TABLE X.

Temperature: 500° C. Time: 9 hours.

Reagents (1 gm. of each)	Microcline (0.5 gm.)
$K_2F_2 + Al_2F_6$	1.25 gm., 80% Phillipsite?
$K_2F_2 + Na_2SiF_6$	0.70 gm., 60% Silica
$Al_2F_6 + Na_2SiF_6$	1.68 gm., 90% Cryolite

The resulting products agree with the corresponding experiments of Group IX.

DISCUSSION.

In agreement with general opinion concerning the activity of hot acid solutions in nature, as stated by Clarke,[41] certain experiments herein described indicate that such solutions attack and decompose in varying degree the rocks and minerals with which they come in contact, producing soluble sulphates or chlorides according to their character. But contrary to the accepted idea that both silica and hydrous aluminum silicates remain behind as residual products in such a decomposition process, it is found that only silica is the principal remainder, the major portion of the

[39] Termier, P., *Bull. Soc. Fran. Min.*, vol. 46, pp. 18–20, 1923; also see Corbett, C. S., *op. cit.*, p. 250.

[40] Larsen, E. S. and Wherry, E. T., *Wash. Acad. Sci. J.*, vol. 7, pp. 208–17, 1917; also Corbett, C. S., *op. cit.*, pp. 250–51.

[41] Clarke, F. W., *op. cit.*, p. 210.

alumina being removed along with the more soluble constituents. This removal of alumina agrees with Lindgren's [42] explanation of a particular phase of alteration of the rocks adjacent to the veins in the De Lamar mine, Idaho; he states: "the loss of so much Al_2O_3 can be explained on the supposition that the waters contained sulphuric acid, as only such thermal waters are known to dissolve alumina in large quantities."

That acid waters do occur in nature is well known, but that they are a factor in processes of rock alteration and ore deposition, other than in the case of cold descending sulphuric acid reactions, is strongly argued against by many geologists. Clarke [43] classifies acid waters as either being derived from sedimentary rocks, their acidity being probably due to the oxidation of pyrite and other sulphides, or as of volcanic origin. Volcanic emanations have been studied by many investigators.[44] That sulphur in the form of sulphur dioxide, sulphur trioxide, hydrogen sulphide and sulphur vapor, and free oxygen, as well as water vapor and other gases, are present in volcanic emanations is shown by the analyses of the gases from Kilauea,[45] of Sulphur Banks,[46] of Mount Katmai,[47] and in older analyses recorded in the literature. Wells [48] has recently discussed the possible formation of sulphur trioxide and sulphuric acid from magmatic sources, referring to numerous equilibria experiments conducted by various earlier investigators.

The combined evidence of analyses showing the presence of sulphuric acid in waters of volcanic origin and those showing the presence of sulphur, sulphur compounds, free oxygen and water

[42] Lindgren, W., "The Gold and Silver Veins of Silver City, De Lamar, and other Mining Districts in Idaho," U. S. Geol. Survey 20th Ann. Rept., pt. 3, p. 181, 1900.

[43] Clarke, F. W., *op. cit.*, pp. 199–200.

[44] See Clarke, F. W., *op. cit.*, pp. 261–92, for outline of data and references.

[45] Day, A. L. and Shepherd, E. S., "Water and Volcanic Activity," *Bull. Geol. Soc. Am.*, vol. 24, p. 588, 1913.

[46] Allen, E. T., *Hawaiian Observatory Bull.*, vol. 10, p. 89, 1922.

[47] Allen, E. T. and Zies, E. G., Nat. Geog. Soc. Tech. Paper, Katmai series No. 2, 1923.

[48] Wells, R. C., "Chemistry of Deposition of Native Copper from Ascending Solutions," U. S. Geol. Sur. Bull. 778, pp. 6–10, 1925.

in volcanic gases, together with the results of equilibria experiments concerning reactions between these various gases would seem to clearly indicate the formation of sulphuric acid in nature by other means as well as by oxidation of sulphides by atmospheric agencies. And if the origin of volcanic emanations is from crystallizing magma, as advanced by Day [49] and others, it seems probable that sulphuric acid may occur in hot ascending solutions and be an important factor in ore deposition, at least in some instances. The chief point of contention is wl ether or not the free acid so formed could long remain uncombined.

Ransome [50] has discussed in connection with the origin of the ore deposits of Goldfield, Nevada, the possible conditions under which sulphuric acid is formed in nature, one of which, "the direct volcanic hypothesis," postulates that the solutions containing sulphuric acid are of deep-seated origin. Butler [51] has ably discussed the conditions for formation of sulphur trioxide, sulphuric acid and primary sulphate minerals, and arrives at the general conclusion "that some of the metals which at high temperatures are combined with oxygen, as the temperature is reduced, give up oxygen, and both the metals and the oxygen combine with sulphur. At suitable temperatures the sulphites and sulphates are doubtless formed and the less soluble sulphates are deposited. Moreover, it is believed that certain conditions lead to the formation of free sulphuric acid which, on reaction with potassium-aluminum rocks, forms alunite." In summation he concludes: "This interchange of oxygen from certain elements at high temperature to sulphur at lower temperature is believed to be an important factor not only in the formation of sulphates in solutions of deep-seated origin but also in the precipitation of primary (hypogene) ore minerals."

Concerning the formation of alunite, Butler [52] further states: "Under favorable conditions and probably at comparatively low

[49] Day, A. L., "Some Causes of Volcanic Activity," an address, The Franklin Institute, September, 1924.

[50] Ransome, F. L., *op. cit.*, pp. 189–95.

[51] Butler, B. S., *op. cit.*, pp. 581–609.

[52] Butler, B. S., *idem*, p. 608.

temperature alunite forms abundantly. In some deposits at least the sulphate radicle of the alunite was probably derived from deep-seated solutions." Clarke[53] states: "Acid solutions, produced by the oxidation of pyrite, act upon aluminous rocks and form sulphates of alumina. Alunite and alunogen are among the commoner species so generated." Experiments here strongly suggest that soluble aluminum sulphate is the principle factor required in an alteration process producing alunite; particularly is this indicated by the fact that aluminum sulphate solution acting alone upon the feldspars produced alunite, while the alkali sulphates and sulphuric acid did not. The production of alunite directly from solution is also shown to be possible and would seem to satisfactorily explain the origin of certain vein deposits of the mineral. In the x-ray patterns the intensity and the lack of multiplicity of the lines indicate the great predominance of alunite over the original feldspar. Also the shifting to the right of lines in patterns in which sodium is present, derived from the feldspar or from the solution used by replacement of potassium, agrees well with the theory of atomic replacement in crystal structures.

Cryolite (Na_3AlF_6), a comparatively rare mineral, is generally considered to be of pegmatitic origin. The formation of this mineral as herein experimentally produced suggests its origin in nature as a result of feldspar or other aluminous mineral alteration and replacement by hydrothermal processes—or perhaps the "hypothermal" of Lindgren[54]—and agrees with the recently suggested origin of the cryolite deposit at Ivigtut, Greenland.[55] Unfortunately the products from which the x-ray patterns were made evidently did not contain a large enough percentage of cryolite to produce lines of very great intensity.

Leverrierite, a hydrous aluminum silicate of rather variable chemical composition, physical and optical properties, has recently

53 Clarke, F. W., *op. cit.*, p. 260.

54 Lindgren, W., "Replacement in the Tin-bearing Veins of Caracoles, Bolivia," ECON. GEOL., vol. 21, pp. 135–44, 1926.

55 Gordon, S. G., "Mining Cryolite in Greenland," *Eng. and Min. J.-P.*, vol. 121, p. 240, 1926.

been discussed by Corbett.[56] The fact that it may closely resemble sericite in composition and other properties suggests a possibly more widespread occurrence of the mineral than commonly thought. It is held to occur as a vein mineral by precipitation from solution, as a product of hydrothermal alteration, as a primary mineral in sedimentary rocks and a secondary one in some schistose rocks. The possible formation of leverrierite in certain of the above experiments, particularly the fibrous variety perfectly resembling sericite in all but refractive index, is significant in that it was produced at 575° C. (Group VIII.) but not at 400° C. (Group VII.), although the beginning of decomposition of the feldspars was apparent at the lower temperature in the potassium carbonate reactions. The sericite-like product resulting from the reaction with fluorides in the above Group VIII. rather suggests that certain fluorides, as well as carbonates or carbon dioxide may be active agents in the alteration of feldspars to sericite. While sericite was not produced in these experiments, the fibrous sericite-like product obtained strongly suggests the possibility of such a result if a slightly higher temperature prevailed.

The leverrierite-like alteration product obtained in Group IX. at 350° C., under atmospheric pressure and with chloride reagents, closely agrees in optical properties with the more commonly known variety of leverrierite, as discussed under the group heading. The fact that a similar product was not also produced by fluorides at this temperature and pressure suggests that this particular variety of the mineral may be formed more readily in the presence of chlorides.

It is notable that kaolin was not produced in any of the experiments of this investigation. However, it can not be denied that a small percentage of the mineral might have been overlooked in the microscopic examination of some of the experimental products, notwithstanding that a careful search was always made. It can at least be definitely stated that kaolin did not result as a principal alteration product in any of the hydrothermal experi-

[56] Corbett, C. S., *op. cit.*

ments performed. From this it appears that the formation of kaolin is due largely to the decomposition and hydration of aluminous minerals exposed to atmospheric agencies, although other possible and unexpected factors, in connection with hydrothermal studies, may yet be discovered which will readily bring about the abundant formation of kaolin under conditions comparable to those of hot ascending solutions in nature.

SUMMARY.

At 100° C. alkali carbonate, chloride and sulphate solutions did not alter the feldspars or spodumene, excepting an apparent slight corrosion of some grains of albite and bytownite in treatment with sulphate solutions. Hydrochloric acid partially decomposed labradorite, producing a small percentage of residual silica. Sulphuric acid apparently did not attack microcline or albite but almost completely decomposed labradorite and bytownite, with only silica remaining as a decomposition product; analyses of fresh and altered minerals are given.

Alunite was produced from feldspars at 22°, 65° and 100° C., atmospheric pressure, and at 200° C., approximately 15 atmospheres pressure, by the addition of aluminum sulphate to sulphuric acid, potassium sulphate and sodium sulphate solutions, and by aluminum sulphate solution alone. Alunite was also formed purely synthetically from mixtures of aluminum sulphate and alkali sulphate solutions. Analyses and a mineral calculation, as well as x-ray diffraction patterns, conclusively prove the identity of the experimental products as alunite or a variety of alunite. Alunite was not formed at 350° C. in water vapor experiments at atmospheric pressure.

Hydrochloric and sulphuric acid reactions at 200° C. and somewhat below 15 atmospheres pressure resulted in partial or complete solution of the feldspar or decomposition with a residual silica product.

Zeolites were formed in reactions between feldspars and alkali carbonate solutions at 200° C. and about 15 atmospheres pressure; also at 350° C. in presence of fluorides and water vapor at atmospheric pressure.

Cryolite was formed from the feldspars in reaction with certain fluorides and water vapor at 350° C., atmospheric pressure, and at 400° and 575° C., under pressures of approximately 8 and 10 atmospheres, respectively. An x-ray pattern is shown.

Products closely corresponding to the variable hydrous aluminum silicate, leverrierite, were formed at 350° C. in the presence of chlorides and water vapor at atmospheric pressure, and at 575° C. and about 10 atmospheres pressure, with fluorides and potassium carbonate. In the higher temperature experiments the product was fibrous and closely resembled sericite.

Kaolin was not produced, at least not in noticeable amounts, in any of the experiments.

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INTERGROWTHS OF CHALCOPYRITE AND CUBANITE: EXPERIMENTAL PROOF OF THE ORIGIN OF INTERGROWTHS AND THEIR BEARING ON THE GEOLOGIC THERMOMETER.

G. M. SCHWARTZ.

INTRODUCTION.

CRYSTALLOGRAPHIC and various other intergrowths of ore minerals have been frequently described since the introduction of the study of polished surfaces. The significance of these intergrowths has been the subject of much discussion and they have been variously interpreted.[1] The writer became interested in some of these intergrowths during investigations of various ores and gradually accumulated evidence as to the probable origin of some of them. This led to experimental work which has definitely proven that so-called crystallographic intergrowths of two minerals may result from a transformation from a solid solution into two phases.

The methods used were microscopic study and X-ray analysis, followed by heat treatment, reëxamination under the microscopic and by X-ray. Retreatment by heat was further utilized to prove that an original structure could be reproduced.

In recent papers [2] the writer has shown cubanite (chalmersite)

[1] Laney, F. B., ECON. GEOL., vol. 6, pp. 399–411, 1911. Singewald, J. T., U. S. Bur. Mines Bull. 13, 1913. Segall, Julius, ECON. GEOL., vol. 10, pp. 462–470, 1915. Ray, J. C., ECON. GEOL., vol. 11, pp. 179–185, 1916. Rogers, A. F., ECON. GEOL., vol. 11, pp. 582–593, 1916. Goodchild, W. H., ECON. GEOL., vol. 11, p. 397, 1916. Whitehead, W. L., ECON. GEOL., vol. 11, pp. 1–14, 1916. Teas, L. F., *Trans. A. I. M. E.*, vol. 49, pp. 8–87, 1918. Schneiderhöhn, Untersuchung von Erzen. Berlin, 1922. Van der Veen, R. W., "Mineragraphy and Ore Deposition." Delft, Holland, 1925.

[2] Schwartz, G. M., "Chalmersite at Fierro, New Mexico, with a note on its occurrence at Parry Sound, Ontario," ECON. GEOL., vol. 18, pp. 270–277, 1923. "Primary Relationships and Unusual Chalcopyrite at Parry Sound, Ontario," ECON. GEOL., vol. 19, pp. 208–213, 1924.

to be much more abundant and important than realized heretofore. The identity of cubanite and chalmersite has been shown by workers in the Geophysical Laboratory.[3]

The mineral has usually escaped notice because of its intimate association with chalcopyrite which it closely resembles, and from which it can, as a rule, be distinguished only on polished surfaces. Further studies in the mineralographic laboratory of the University of Minnesota have shown that cubanite is also common in the ores at Ducktown, Tennessee, and in the Oiseau River district, Manitoba. Specimens have been examined from five districts including besides those noted above, Prince William Sound, Alaska. A specimen from this district was obtained through the kindness of Dr. B. L. Johnson of the United States Geological Survey.

Ramdohr [4] has also described the mineral in several foreign deposits.

In the paper on the Fierro ores the writer has described the intergrowth of chalmersite (cubanite) in chalcopyrite.[5] Examination of ores of the other occurrences listed above shows that this relation of cubanite and chalcopyrite is found in each, and is in fact characteristic of the mineral as has also been shown by Ramdohr.

Acknowledgments are due to Professor O. E. Harder and Mr. R. L. Dowdell of the Department of Metallography for suggestions and assistance in the experimental work and to Professors W. H. Emmons, F. F. Grout and J. W. Gruner of the Department of Geology for suggestions and criticism.

SUMMARY OF OCCURRENCE OF ORES STUDIED.

The following summary of the occurrences studied by the writer gives the essential facts as to the type of deposit and as-

[3] Merwin, Lombard and Allen, "Cubanite, Identity with Chalmersite," *American Mineralogist*, vol. 8, pp. 135–138, 1923.

[4] Ramdohr, P., "Beobachtungen am Chalmersit," *Metall und Erz*, XXII., 1925, pp. 471–474.

[5] Econ. Geol., vol. 18, plate X.

sociated minerals. Their general similarity is doubtless of significance.

Fierro, New Mexico.—The deposits consist principally of magnetite of contact metamorphic origin. Within the magnetite ores are masses of sulphides. The common minerals are magnetite, pyrrhotite, chalcopyrite, cubanite, pyrite and sphalerite. The cubanite is found only as intergrowths with chalcopyrite in the form of laths and areas with straight boundaries. (See Figs. 1–6.) Pyrrhotite, at least in part, crystallized later than the chalcopyrite-cubanite intergrowth.

Parry Sound, Ontario.—The deposits are impregnations or replacements in schist and are of the deep zone type. The common ore minerals are magnetite, chalcopyrite, pyrrhotite, cubanite, pyrite and sphalerite. Pyrrhotite is apparently both earlier and later in crystallization than the chalcopyrite, but in specimens containing the chalcopyrite-cubanite intergrowth the pyrrhotite seems to have crystallized later.

Ducktown, Tennessee.—These deposits are also of the deep zone type and are replacements in schists. The principal minerals are pyrrhotite, pyrite, chalcopyrite, sphalerite, magnetite, and galena. Cubanite was discovered in several specimens and has to the writer's knowledge not been reported previously from this district. The mineral occurs only as lath-like intergrowths in chalcopyrite. Pyrrhotite seems to have crystallized both before and after the chalcopyrite-cubanite intergrowth.

Oiseau River District, Manitoba.[6]—These deposits are near or in a norite or gabbro intruded in schists. The deposits are said to be similar to those at Sudbury, but most of the sulphides are obviously later than the rocks in which they are found. The ore minerals are: pyrrhotite, pyrite, magnetite, sphalerite, polydmite, pentlandite, chalcopyrite, and cubanite. The cubanite is found as laths in the chalcopyrite. (See Figs. 1–6.)

[6] Colony, R. J., "A Norite of the Sudbury Type in Manitoba," *Trans. Can. Inst. M. and M. Eng.*, 1920. DeLury, J. S., "Mineral Prospects in Southeastern Manitoba," Manitoba Government Bulletin, 1921. McGann, W. S., "The Maskwa River Copper-nickel Deposit," Geol. Sur. Canada Summary Report 1920, Part *C*. Cooke, H. C., "Geology and Mineral Resources of Pine Lake and Oiseau River Areas," Geol. Sur. Canada Summary Report 1921, Part *C*.

Prince William Sound, Alaska.[7]—The copper deposits in which cubanite (chalmersite) is found are principally in greenstone and are of the deep zone type. The minerals are chalcopyrite, cubanite, pyrrhotite, sphalerite, galena, pyrite, arsenopyrite, gold, silver, etc. Cubanite is intergrown with chalcopyrite according to Johnson, and was found by the writer as characteristic bladed intergrowths.

DISCUSSION OF FACTS OF OCCURRENCE.

It has been noted above that in specimens from each of the five districts cubanite occurs as an intergrowth with chalcopyrite. Figs. 1–6 give an idea of some of these textures. All specimens show cubanite distributed as laths or bands which are in parallel sets. In many specimens only one set of bands are visible, as in Fig. 1, but in other specimens two or three directions of intergrowth may be recognized as in Figs. 2, 3, 4. That the intergrowths represent a true crystallographic relation is indicated by the sharp contacts between the two minerals, the diagrammatic regularity and straightness of the intergrowths, the lack of replacement relations, and by the fact that the laths at any one place are either parallel or in parallel sets which make angles approximating 60° with one another. (See Fig. 2.) The last fact suggests to the writer that the blades or laths are parallel to the parting planes which may be conspicuously developed in chalcopyrite found with cubanite as at Parry Sound.[8] Fig. 2 shows the laths following the direction of the parting in a specimen of the Fierro ore and the partings free from cubanite may also be recognized.

It seems to the writer that this unusual texture must have some significance as regards the formation of the minerals. Facts of importance are:

1. The mineral cubanite is characteristically found only in high temperature deposits; *i.e.*, deep zone, contact metamorphic, and possibly magmatic segregation deposits. Ramdohr has noted this in the deposits described by him.

[7] Johnson, B. L., "Preliminary Note of the Occurrence of Chalmersite in the Ore Deposits of Prince William Sound," ECON. GEOL., vol. 12, pp. 519–525, 1917.

[8] Schwartz, G. M., "Primary Relationships and Unusual Chalcopyrite at Parry Sound, Ontario," ECON. GEOL., vol. 19, pp. 209–213, 1924.

MICROGRAPHS OF CHALCOPYRITE-CUBANITE INTERGROWTHS AND SOLID SOLUTIONS.

FIG. 1. Intergrowth of cubanite (light) and chalcopyrite. Mainly in one direction. Fierro, New Mexico. × 50.

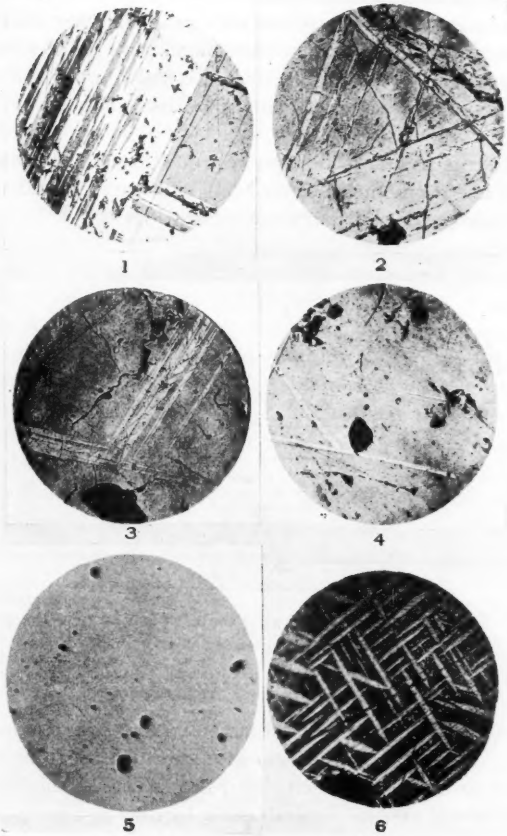
FIG. 2. Laths of cubanite along three directions of parting in chalcopyrite. Some partings are without cubanite. Fierro, New Mexico. × 17.

FIG. 3. Cubanite blades in two directions in chalcopyrite, Wilcox mine, Parry Sound, Ontario. × 35.

FIG. 4. Cubanite laths in chalcopyrite in three directions. Oiseau River district, Manitoba. × 35.

FIG. 5. Specimen from Fierro much like Fig. 1, heated to 650° C. and cooled quickly. Cubanite has dissolved in chalcopyrite, leaving a homogeneous mineral. × 450.

FIG. 6. Half of same specimen as Fig. 5, reheated to 650° C. and cooled slowly (28 hours). The two phases have separated. Light blades are cubanite along the possible direction of parting in chalcopyrite. × 450.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3. Cubanite is not intergrown with minerals other than chalcopyrite, although other minerals are abundant in the ores studied.

4. Pyrrhotite is in all cases an associated mineral and often crystallizes somewhat later than the cubanite-chalcopyrite intergrowth.

5. There is a close relation between the minerals chalcopyrite, cubanite and pyrrhotite, cubanite being in a way intermediate between chalcopyrite and pyrrhotite. (See Fig. 7.)

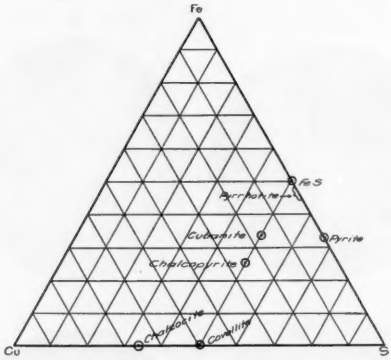

FIG. 7. Triangular diagram showing the composition of chalcopyrite, cubanite and pyrrhotite expressed in atomic per cent.

INFERENCES AS TO FORMATION.

To explain the manner of formation of the intergrowths it is necessary to start with the nature of the solution from which precipitation or crystallization took place. In most sulphide ore deposits several sulphide minerals occur together in a more or less intimate manner, but as a rule there is evidence of a successive crystallization, and crystal intergrowths are relatively not abundant as may be seen by referring to the numerous microscopic

[9] *Op. cit.*, Figs. 176–179.

studies of ores published in recent years. Later minerals corrode earlier ones, cut them in veinlets, or replace them along cleavage cracks and so on. There are, however, exceptions to the normal successive crystallization of minerals as in the case of intergrowths of ilmenite and magnetite; stannite and chalcopyrite; sphalerite and chalcopyrite, and others, which it has been suggested, have formed by the breaking down of solid solutions.[10]

There are indications in the data given above that a similar explanation may serve in the case of the intergrowths of chalcopyrite and cubanite, in fact Ramdohr has suggested this in the paper cited above. The intergrowths shown in Figs. 1–6 resemble textures commonly formed as the result of breaking down of solid solutions of certain alloys, but aside from this no proof has been given that such intergrowths in minerals represent the result of such a process.[11] A mutual solubility of the constituents of chalcopyrite, cubanite, and probably pyrrhotite, before they reached the solid state, and of a solid solution of chalcopyrite and cubanite might be expected from the close chemical relations of the three minerals as shown in the following table and by Fig. 7. Palache[12] has expressed the opinion that chalmersite (cubanite) is composed of the chalcocite (Cu_2S) and pyrrhotite (Fe_4S_5) molecules.

Mineral.	Formula.	Composition.			Crystal Form.
		Cu.	Fe.	S.	
Chalcopyrite....	CuS.FeS	34.50	30.50	35.00	Tetragonal (sphenoidal)
Cubanite.....	$Cu_2S.Fe_4S_5$	23.42	41.14	35.44	Orthorhombic
Pyrrhotite.....	Fe_4S_5 or FeS+S	.....	58.30	41.70	Hexagonal (orthorhombic above 138° C.)

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Figure 7 shows the atomic per cents of the three minerals under consideration as well as those of the simple copper sulphides which may be present as molecules in the complex copper-iron sulphides. It may be seen that the atomic percentage of sulphur is constant in the three minerals under consideration. The essential difference between chalcopyrite, cubanite and pyrrhotite is the progressive replacement of copper by iron. If FeS is considered instead of pyrrhotite (FeS + S) then the atomic per cent. of sulphur remains at 50 per cent.

A glance at the triangular diagram (Fig. 7) shows that the solution from which the three minerals crystallized must have had a composition between chalcopyrite and pyrrhotite, perhaps near that of cubanite. In some of the specimens from Fierro the writer estimated under the microscope an approximate mineral composition of 50 per cent. chalcopyrite and 25 per cent. each of cubanite and pyrrhotite. Recalculating this back to weight per cents of copper, iron and sulphur, the result is found to correspond almost exactly with the composition of cubanite. Thus it is apparent that material of the composition of cubanite does not necessarily crystallize as cubanite, but results eventually in a mixture of three minerals. Considering the cooling of such a solution, it is probable that as crystallization took place at high temperatures, material of the composition of cubanite was in solution in chalcopyrite. An excess of iron and sulphur crystallized as pyrrhotite, perhaps at somewhat lower temperatures, and slightly later than the chalcopyrite-cubanite solid solution. The pyrrhotite at Fierro obviously crystallized later than the chalcopyrite-cubanite intergrowth.[13] As the temperature of the ore gradually lowered a metastable condition was produced in the solid solution and finally the two phases, chalcopyrite and cubanite, separated. Chalcopyrite probably has the stronger crystallizing power and the cubanite was forced to a position along the parting planes which may be well developed as previously shown by the writer.[14]

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EXPERIMENTAL DATA.

Practically all of the facts and theory as outlined above were deduced as a result of observations on ores and reasoning from them. It occurred to the writer that it should be possible to prove experimentally whether or not chalcopyrite and cubanite form a solid solution at high temperatures and if a bladed intergrowth forms when they are slowly cooled. With the aid of Dr. O. E. Harder and Mr. R. L. Dowdell of the Department of Metallography of the University of Minnesota, a series of experiments was outlined. These were carried out with the assistance of Mr. Dowdell.

The first difficulty in working with sulphides is the prevention of oxidation. This is especially so in the present case where pyrrhotite and the pyrrhotite molecule are being considered. A small loss of sulphur might greatly affect results, as pyrrhotite is considered by many to be a solid solution of S in FeS. In the preliminary experiments it was desired to treat a number of specimens at various temperatures at one time in order to obtain results on which to base more detailed experiments. For this purpose small specimens of ore showing the chalcopyrite-cubanite intergrowth from Fierro and the Oiseau River district, Manitoba, were polished and ground down so that they might be inserted in silica tubes with about ¾-inch inside dimensions. The tubes were sealed at one end in a large electric arc, then cooled and the specimen inserted and the other end sealed. The first tubes were evacuated, but the small amount of air in them was not found objectionable and this difficult part of the experiment was omitted in later work.

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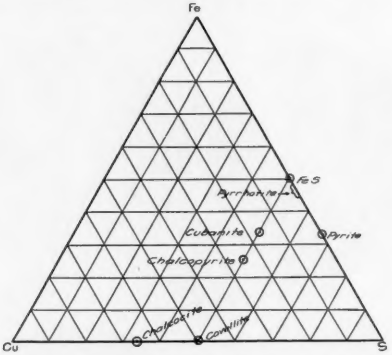

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The tubes were inserted in an electric furnace equipped with a thermo-couple for temperature determination. Specimens were

withdrawn at 500° C., 700° C., and 900° C. and quenched in water after holding at the lower temperature for one hour and the higher ones for one-half hour each. The specimens were mounted in sealing wax for repolishing where the drastic quenching had caused fracturing.

In the specimen heated to 500° C., the two minerals were still apparent, although it appeared that there was some solution. In all of those heated above 500° C. the original intergrowth disappeared and an apparently homogeneous mineral remained that resembles, but is somewhat lighter in color than normal chalcopyrite. (See Fig. 5.)

Examination with an oil immersion lens at magnifications of 1,000 failed to resolve the mineral into two components. Microscopically it may be considered homogeneous. Later determination by the X-ray method showed it to be truly homogeneous.

The next step was to determine any possible heat effects as the samples are heated and cooled. For this purpose a small platinum wound-tube furnace with a General Electric oil-vacuum pump attached was utilized. This was equipped with a large Weston potentiometer for accurate temperature determination. The specimens were wired securely to the thermo-couple and placed in a silica tube which was kept evacuated by means of the pump. The temperature was slowly raised and readings taken according to the usual procedure in thermal analysis for plotting an inverse rate curve. No well defined points at which heat was absorbed or evolved were noted either on heating up to 665° C. or on cooling from that temperature. Although several check runs would be necessary to establish the absence of definite heat effects, it seems quite probable that they are not important enough to be recognized. This is due either to a very sluggish inversion or to the fact that solution is gradual and solubility is a factor of both time and temperature. Examination of the specimens thus treated showed that a solid solution was formed but the two phases were not reprecipitated on cooling.

This indicated that a much slower cooling was necessary. Accordingly one of the specimens of the solid solution was sawed

in two, and with two new specimens was reheated in the same furnace at 650° C. This temperature was reached at 9 A.M. and the cooling was carried on at the rate of 50° C. per hour until 4 P.M. It was then held at 450° C. $\pm$ 5° until the next morning when it was stepped down 50° per hour to about 300° C., and then allowed to cool to about room temperature in an hour.

Examination with an oil immersion lens readily showed the existence of two phases as shown in Fig. 6. All three specimens showed the same characteristic structure eliminating any chance of error. Each specimen was polished and carefully studied before treatment and only a small amount of repolishing was required after heat treatment.

It was later found that specimens heated for a number of hours at a temperature of 450° C. to 500° C. would dissolve the original intergrowth and then reprecipitate a very fine intergrowth on air cooling. It is wise, therefore, to quench all specimens in water when it is desired to hold the solid solution phase.

In order to determine more definitely the temperature at which the solid solution would form, more experiments were necessary. Inasmuch as the temperature range required was below 650° C. it was decided that pyrex glass could be substituted for the silica tubes. This proved very satisfactory and the manipulation was much easier.

The first step was to determine if the solid solution would form at 500° C. if held a longer time. In the original experiment this temperature was held for one hour. A second trial holding at 500° C. for four hours resulted in an apparently perfect solution. Runs were then made at 450° and 475° C. for five hours. At 450° C. the specimen showed a fading of the boundaries but the major part of the cubanite remained. At 475° C. in five hours solution was nearly complete. The laths of cubanite had disappeared but the color of the specimen was not quite even, suggesting that a somewhat longer time would be necessary to obtain a completely homogeneous solid solution. Thus the temperature at which the solid solution will form in five hours is fixed between 450° and 475° C.

It was then decided to investigate the importance of the time factor somewhat farther. Consequently a specimen was held at or just below 450° C. for a week with apparently complete solution as a result. The experiment was repeated at 400° C. for a week. In this case there was apparently no effect except possibly some slight action along contacts as some of these seem less sharp than in the fresh specimen, although the color difference between chalcopyrite and cubanite is so slight that the two are never very distinct.

It may be concluded that the two phases dissolve on heating at somewhat above 400° C. and definitely below 450° C. It seems unlikely that holding for a longer time at 400° C. would result in solution as there is no appreciable effect in a week. It is probable that at, or below 400° C. the mobility of the atoms is so slight that solution practically ceases.

In order to check the results still farther X-ray diffraction patterns were obtained of finely powdered material of specimens in the original state, after heating followed by quenching, and after reheating with the slow cooling described above. The results are shown in Fig. 8. For comparison patterns were ob-

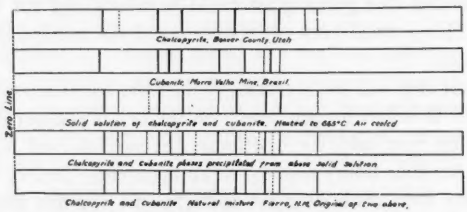
Chalcopyrite, Beaver County, Utah
Cubanite, Morro Velho Mine, Brazil
Zero Line
Solid solution of chalcopyrite and cubanite. Heated to 665°C. Air cooled
Chalcopyrite and cubanite phases precipitated from above solid solution
Chalcopyrite and cubanite Natural mixture Fierro, N.M. Original of two above.

FIG. 8. Diagram of the X-ray diffraction patterns of the minerals and mixtures studied.

tained of apparently pure chalcopyrite from Beaver County, Utah, and cubanite from the Morro Velho mine, Brazil. The cubanite was obtained through the kindness of Dr. Charles Palache of Harvard University, and consisted of fragments of crystals from the same specimen as the type crystals described by Dr. Palache.[15]

[15] *Op. cit.*

The X-ray data served to check the results determined by the microscope. The opinion that cubanite would be taken in to the space lattice of chalcopyrite as was predicted from the relationships described earlier in this paper, was proven correct by the almost exact correspondence of the diffraction patterns of chalcopyrite-cubanite solid solution. That a solid solution was formed is clearly shown by comparing the pattern of the original mixture of chalcopyrite and cubanite from Fierro, with that which has been heated and quenched to prevent the breaking down of the solution. That the two phases are reprecipitated by slow cooling is equally well shown by the fourth pattern. It should be noted that there is one prominent line in this pattern not shown in the others. An explanation of this is not obvious, but it is apparently due to a third mineral present, probably pyrrhotite. In conclusion it may be stated that the X-ray analyses checked with the microscopic data in every respect. This method has apparently removed all possible doubts as to what happened during the experiments.

EXPLANATION OF THE STRUCTURE OF THE INTERGROWTH.

There is, naturally, a distinct difference in the texture produced by heat treatment and the original. This is brought out in Figs. 1–6. The natural intergrowth is much coarser and, where cubanite is abundant as in Fig. 1, areas are present which are not necessarily controlled by the chalcopyrite structure. As a rule, however, the cubanite as long laths is oriented along the (111) planes in the chalcopyrite. In the artificial structure the cubanite is likewise oriented along these planes, but occurs as minute discontinuous blades. Undoubtedly the rate of cooling is the most important factor determining this difference in texture, but variations in pressure, the presence of gases and liquids and other factors may also be important.

It is obvious that the cubanite is oriented along the sphenoid (111) planes in the chalcopyrite, and the writer[16] has shown that chalcopyrite may show well developed parting along the same

[16] Schwartz, G. M., Econ. Geol., vol. 19, pp. 209–213, 1924.

planes. Recently the parting has been recognized in a specimen of chalcopyrite from Globe, Arizona, where replacement of chalcopyrite by bornite was controlled by the parting.

As a rule planes of parting are related to the arrangement of the atoms in the space lattice of the crystal. The chalcopyrite space lattice has been studied and fairly dependable results are available.[17]

The lattice illustrated in Wyckoff's text is probably correct and it should be possible to find an explanation of the parting in the arrangement of the atoms. A study of a model of the lattice reveals such a probable explanation. Chalcopyrite is tetragonal-sphenoidal (Dana's classification) in crystallization but varies only slightly from the isometric-tetrahedral. For practical purposes the difference need not be considered. If the grouping of the atoms in the (111) planes is considered it is obvious that

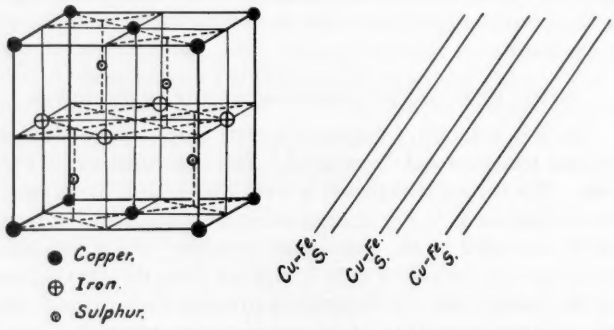

FIG. 9. Sketches showing the space lattice of chalcopyrite and spacing of the (111) planes.

there is an unequal spacing of the parallel planes. (See Fig. 9.)

To visualize this arrangement more than one unit cell should

[17] Wyckoff, R. W. G., "The Structure of Crystals," Am. Chem. Soc., Monograph Series, 1924, p. 365. Burdick and Ellis, "X-ray Examination of the Crystal Structure of Chalcopyrite, *Proc. Nat. Acad. Sci.*, vol. 3, p. 644, 1917; *Jour. Am. Chem. Soc.*, vol. 39, p. 2518, 1917. Gross and Gross, "The Atomic Arrangement of Chalcopyrite," *Neues Jahrb. Min. und Geol.*, vol. 48, p. 77, 1923.

be viewed. One may see then such spacing of planes as shown by the parallel lines of Fig. 9. Each copper-iron plane is followed by a sulphur plane at a distance of 1/6.968 of the edge of the unit cell; but the distance between two such sets of Cu-Fe and S [18] planes is three times as large (1/2.323).

It seems logical to assume that the plane of parting corresponds to the greater space between planes. It may be further observed from the model, or be computed, that this is the greatest interplanar distance in the whole lattice of chalcopyrite. Not only would this space result in parting, but it would also offer the easiest plane for the cubanite to align itself when the solid solution breaks down. Therein lies the most probable explanation of the texture figured.

DISCUSSION.

That many textures found in opaque ore minerals are a result of transformation in a solid solution is not a new idea. This is, however, the first case to the writer's knowledge where the origin has been proven by experiments performed on natural minerals thus forming a solid solution and reprecipitating the two phases. European geologists have been particularly favorable to the idea, notably Schneiderhöhn and Van der Veen.[19] It is difficult, however, by the very nature of the case, to be certain and the writer would suggest that considerable caution be used in assigning structures to this cause without the necessary experimental data. It is the writer's opinion that some of the cases assigned by Van der Veen to this origin were probably formed by replacement. Newhouse [20] has recently drawn attention to this problem and his statements are strongly seconded. Preliminary experiments have indicated that transformations in a solid state will serve to explain other intergrowths but much more data are necessary to be certain. Experiments to that end are being carried out as time

[18] For computations of such distances see any book on crystal structure.

[19] *Op. cit.*

[20] Newhouse, W. H., "An Examination as to the Intergrowths of Certain Minerals," ECON. GEOL., vol. 21, pp. 68–69, 1926.

permits. Recently Wandke[21] reported preliminary experiments along this line.

One of the points not previously touched on is the extent of the solubility of cubanite and chalcopyrite. It is quite probable that the two are soluble in nearly all proportions at moderate temperatures. Some of the specimens treated have a ratio of about 50:50 of the two minerals. These seem to dissolve completely. Undoubtedly the space lattice of chalcopyrite would fail to control when the amount of cubanite became much greater than that of chalcopyrite. Further work on this point depends on securing suitable specimens, which is difficult.

These experiments seem to have a bearing on the geologic thermometer. It seems probable that deposits in which crystallographic intergrowths of chalcopyrite and cubanite are found must have formed at temperatures above 400° C. as the coarse structure indicates a considerable degree of mobility of the atoms during formation. The solid solution of chalcopyrite and cubanite may be formed by heating to 450° C. for a week, but not at 400° C. Precipitation and solution occur at the same points on cooling and heating. Thus slow cooling of a solid solution heated to above 450° C. will result in the precipitation of the two phases. Heating to 400° C. and slow cooling would produce no results.

The estimate of a minimum of 400° C. for the formation of these deposits agrees with Lindgren's[22] estimate of a temperature for high temperature deposits of less than 575° C. and higher than 300° C. Further work along the lines begun in this paper will add much to our knowledge of the temperatures at which ore deposits have formed.

Another observation made by the writer during the work is that chalcopyrite associated with cubanite seems to have a somewhat lighter color than that from deposits where cubanite does not occur. It is probable that this is due to more or less dissolved cubanite which does not precipitate at ordinary temperatures. This sort of relation is found in the constitution diagram Type

[21] Wandke, A., ECON. GEOL., vol. 21, pp. 166–171, 1926.

[22] Lindgren, W., "Mineral Deposits," p. 613, 1913.

II. *b*.[23] Detailed work will undoubtedly be done in the future which will either verify or disprove this inference.

Fairly complete knowledge regarding transformations, temperature at which they take place, and conditions of equilibrium between various minerals will only be available when the constitution diagrams of the various systems are worked out. This is a tedious and difficult problem, perhaps impossible in some cases, but very fruitful in those cases which can be successfully completed. The Geophysical Laboratory workers have done much along this line on the silicate minerals.

CONCLUSIONS.

1. Cubanite ($CuFe_2S_3$) occurs as far as observed only in close association with chalcopyrite and pyrrhotite.

2. In its chemical and physical characteristics it is intermediate between chalcopyrite and pyrrhotite.

3. Cubanite usually occurs only as lath-like intergrowths along four planes of parting in chalcopyrite.

4. The mode of occurrence of cubanite suggests that it was formed by transformation from a solid solution with chalcopyrite.

5. It was proven by heating and cooling experiments that a solid solution could be formed from the natural intergrowth of chalcopyrite and cubanite at 450° C. and that by slow cooling the two mineral phases could be reprecipitated.

6. The reprecipitated minerals show a similar control of the texture by the structure of the chalcopyrite. An explanation for this is suggested on the basis of the space lattice of chalcopyrite.

7. It is almost certain that the deposits in which the intergrowth is found were formed above 400° C. and probably they formed above 450° C.

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[23] Hoyt, S. S., "Principles of Metallography," p. 20, New York, 1920.

COALS OF SHENSI AND EAST KANSU, CHINA.

MYRON L. FULLER AND FREDERICK G. CLAPP.

INTRODUCTION.

ALTHOUGH several coals in Shensi and eastern Kansu have long been mined by the natives and their existence well known to the Chinese officials and mining companies, they have seldom been mentioned except in books of travel, and have received little or no attention from foreigners. This is in part the result of the inaccessibility of the coal outcrops, which are from 150 to 400 miles from the nearest railroad in a direct line, and from 175 to 500 miles by "roads," the latter for the most mere mule trails of the worst description. The lack of attention is also in part due to the overshadowing of the Shensi coals by the thicker, more numerous, and long mined beds of Shansi, especially those of the eastern half, some of which are within a few miles of railroads and have received the attention of numerous geologists. Several, including ourselves,[1] have made estimates of the available tonnage in eastern or western Shansi.

In 1914 and 1915, we and our associates, including Frank A. Herald, V. H. Barnett, E. L. Estabrook, and Ernest Marquardt, made from 6,000 to 8,000 miles of reconnaissance traverses across Shensi and adjoining parts of Shansi and Kansu in connection with economic investigations for American clients. As in Shansi, the investigation of the coals was not within the province of our studies, but in the mapping of the region, coals were naturally encountered and the areas of the coal-bearing formations approximately determined. So far as known, we were the first geologists to penetrate and cross the region, although Richthofen, Willis, and Blackwelder skirted it on the south. The paleontological ex-

[1] "Revision of Coal Estimates in West Shansi, China," ECON. GEOL., vol. 21, pp. 743–756, 1926. (Includes review of previous estimates.)

aminations by members of the China Geological Survey were not made until some years later.

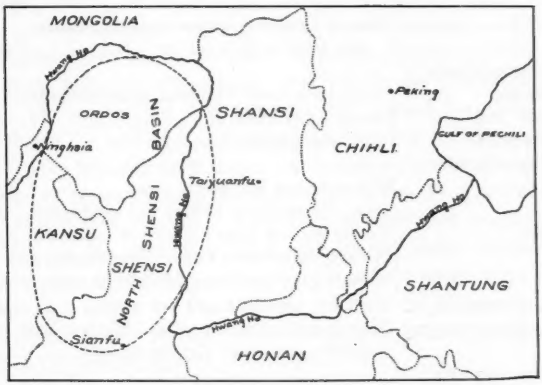

FIG. 1. Sketch map of northeastern China, showing location of the North Shensi Basin.

The coals occur in what is known as the North Shensi Basin, a great trough rimmed by ancient crystalline rocks and filled with deposits from Cambro-Ordovician to Jurassic in age. The coals are found in two formations, the older, which is at least in part of Carboniferous age, forming a ring just inside the rim of the basin, and the younger occurring in the middle of the great series of Jurassic sediments of the central part of the basin.

STRATIGRAPHY.

The succession and characters of the formations[2] of the North Shensi Basin, as determined by us, are concisely presented in the following abbreviated geological column.[3]

[2] The Chinese national, provincial, and town names are commonly written in English as single words, but we follow Willis and Blackwelder in the more correct practice of separating the formation names based on the foregoing into their component parts. The usage of the China Geological Survey varies in its English texts.

[3] A complete section will be found in the *Journal of Geology*, vol. 34, pp. 437–438, 1926. A full discussion of the geology of the North Shensi Basin will be submitted for publication by the Geological Society of America.

GEOLOGICAL COLUMN FOR NORTH SHENSI BASIN.

		Thickness (Feet)
Recent	Recent loess and stream alluvian; dunes and gravels on loess, etc.	Variable
Unconformity		
Pleistocene	Main loess body (Internal unconformities)	1,500
Tertiary and Cretaceous	Basal sandy loess, etc.	500
	Sub-loess gravel	1,000
Unconformity		
Jurassic	Hwan-ho red and green shales	3,000
	Hwa-chi regularly bedded red sandstones	1,000
	Lo-ho massive false bedded red sandstone	2,000
	An-ting limestone (I-chun conglomerate)	200
	Shen-si gray sandstones with local coals	6,000
Permo-Triassic	Pu-hsien sandstone and red shale	2,000
Permo-Carboniferous	Shan-si coal measures (Top, Permian; base, middle and lower Carboniferous)	1,000
Unconformity		
Cambro-Ordovician	Ki-chou limestone	5,000
	Tung-chuan quartzite, etc.	500
Unconformity		
Algonkian	Schists, etc., with internal unconformities.	
Unconformity		
Archean	Gneisses, schists, intrusive granites, etc.	

STRUCTURE.

The North Shensi Basin extends from the vicinity of the great northern loop of the Hwang Ho in the northern Ordos to the east-west Tsin Ling-Ta Hua mountain ranges south of Sianfu in central Shensi, and from western Shansi to eastern Kansu.

Sharply folded and often shattered Archean and Algonkian beds constitute a nearly continuous belt around the basin. Between these and the rim of the basin proper, is a zone of grabens.* mainly in the thick Ki-chow limestone, in many of which the overlying coal measures still remain. These have been observed on the east, south, and west, and they presumably also occur on

* While spoken of as grabens, the faulting is sometimes subordinate to the folding, and the basins may be better described as faulted synclines. Occasionally faults are found only on one side of the basins.

the north side of the basin. Immediately inside the rim of the latter, the Ki-chow (Cambro-Ordovician) limestone, usually considerably faulted, forms another almost continuous ring. The Shansi coal measures, overlying the Ki-chow limestone, and likewise dipping inward into the basin, probably occur on all sides of the trough, although not actually observed in the Ordos on the north. The succeeding Pu-hsien beds dip toward the center of the basin on the east and south, but were not seen on the west or north. The Jurassic formations dip successively westward, the later ones often overlapping the earlier, as well as the Carboniferous, Permian, and Triassic. They are apparently not repeated by upturning on the west, but either end against faults separating them from the older beds, or overlap the latter beneath the 1,000 to 2,000-foot mantle of loess which obscured the contacts at all points visited by the writers. The Cenozoic beds need not be discussed in the present paper.

HISTORY.

Only a few of the many events of the geologic history will be touched upon here. A slight downwarping of the region occurred in Cambrian times but the deepening which led to the formation of the North Shensi embayment or basin took place after the close of the Ki-chow deposition, and mainly after the accumulation of the coal measures. It was accompanied in Permo-Mesozoic times by folding and igneous intrusions contemporaneous in part with Jurassic deposition. The latter was followed by a westward tilting, the faulting of the basin beds, and the bevelling of their outcrops in the long period of Cretaceous erosion which reached an old age or peneplane stage, although the mountains surrounding the basin were not entirely eliminated. In late Tertiary and extending through Pleistocene time, came the deposition of the 500 to 2,000-foot mantle of loess. Faulting and warping became active in the early Pleistocene and has continued to the present time. The upthrows brought the mountains of Shansi, central Shensi, and eastern Kansu to their present heights, while the downthrows gave rise to the marginal grabens constituting the smaller coal basins.

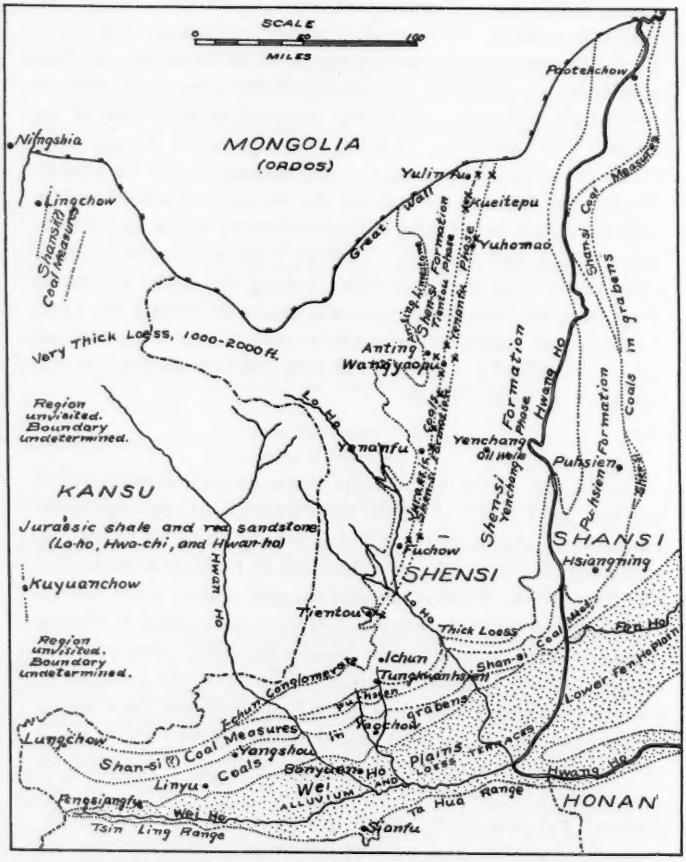

FIG. 2. Map showing distribution of coals in the North Shensi Basin.

PERMO-CARBONIFEROUS COALS.

Introduction.—Under the head of Permo-Carboniferous coals are included those of the Shan-si formation, which lies directly but unconformably upon the Ki-chow limestone around the rim of the North Shensi Basin. The Shan-si was originally regarded as wholly Carboniferous on the basis of plant remains associated with its more conspicuous coals, but recent paleontological collections by the Geological Survey of China from the coal measures near Taiyuanfu and Paotehchow in Shansi, indicate that the upper portion, separated from the lower by a slight disconformity, is of Permian age. The bureau mentioned applies the name Yueh-men-kou to the coal measures as a whole, restricting the term Shan-si to the Permian portion, and giving the new name Tai-yuan-fu (Fig. 2) to the basal, or middle and lower Carboniferous portion. We here follow Willis and Blackwelder in using Shan-si as the name of the lithologic group carrying the coals.

The workable coals occur in both the upper and lower divisions of the formation, with perhaps a greater average thickness in the upper of the two, although there are notable exceptions to this rule.

Character of Coal Measures.—In the province of Shansi, where the thickness ranges from 300 to 1,000 feet, the Shan-si, or coal-bearing formation consists, where fully developed, of a basal division of alternating sandstones and shales, a middle section of black shales, coals, limestones and sandstones, and an upper division of sandstone with little shale or coal. In places, because of the irregular surface upon which the formation rests, only a portion of the lower division has been deposited, and the coals are found very near the base. The unconformity is mainly erosional and there is little discordance of dip. At the top, the formation merges into the Pu-hsien by gradual transition.

On the south rim of the North Shensi Basin in central Shensi the formation as a whole is decidedly more sandy than in Shansi, with considerable thicknesses of a coarse green, often cross-bedded sandstone resembling the Pocono of the United States and quite different from the buff sandstones of Shansi. The percentage of

shale appears to be much less than in the latter province, and coals, although still of workable thickness, appear to be less numerous and thinner. Certain physical characteristics of the beds of the south rim suggest that they may be the equivalent of the upper or Permian portion of the Shan-si formation alone.

On the western rim of the basin the coal measures were noted at three points. No opportunity for the collection of fossils presented itself, but the prevalence of green sandstones, the location of the outcrops near old upturned limestones presumably the equivalent of the Ki-chou, the marked folding, and the shattering of the beds by faulting all appear to point to their being the equivalent of the sandstones on the south, if not also on the east rim of the basin. It is probable that the coal measures lie in grabens rather than in the North Shensi Basin itself.

Coals of Eastern Shensi.—Eastern Shensi, from the Great Wall at the northeast corner southward to the mouth of the Fen Ho, 60 miles north of the Great L-bend at the Honan border, is underlain by the coals of the Shan-si formation, the marginal outcrops of which lie from 0 to 45 miles east of the river. As stated in another paper,[4] about 5,600 square miles of coal measures belonging to the North Shensi Basin are included within the province of Shansi. This, on the basis of an average aggregate thickness of 20 feet of coal, would be equivalent to about 128 billion tons of 2,000 lbs. each.[5] There is an additional 82 billion tons in grabens having an area of 3,400 square miles.

Near the Great Wall, the base of the coal measures is near the water level of the Hwang Ho. Thirty miles to the south, near Paotehchow, the lower beds have gone under, and the river is flowing near the top of the formation. Continuing south, the entire thickness of the coal measures sinks until, in latitude 37°, the top of the coal series is probably 2,500 feet below the river, with the workable coals several hundred feet lower. From this point they gradually rise until the top of the formation reappears

[4] "Revision of Coal Estimates for West Shansi, China," ECON. GEOL., *loc. cit.*

[5] In this and in our previous paper we have, for purposes of easy comparison, used Richthofen's value of approximately 1.37 as the specific gravity of all coals.

in the river bed 30 miles or more above the mouth of the Fen Ho, and the base about 10 miles north of the same river.

At the northerly exposures, in the Paotehchow region, there are nearly a dozen coals ranging from a few inches to 5 feet in thickness, with local thickenings up to 36 to 67 feet (20 meters).[6] The thicker seams, which are a little below the middle of the formation, are worked on a moderate scale.

In the south, along the Hwang Ho above the Fen Ho, there are a similar number of seams, mostly in the lower half of the formation. Some of these are worked, although most of the coal, much of which is shipped down the river, comes from a 15 foot bed near Hsiangning, 25 miles to the northeast. The latter is a coaking coal.

The coals in the area intervening between the northern and southern exposures are of similar number and character. We have placed the probable average total workable thickness at 20 feet, notwithstanding local thickenings to 67 feet or more.

The Shan-si coals extend indefinitely westward beneath the Pu-hsien and Shen-si beds of Shansi and Shensi, the average inclination decreasing from 3° and upward at the inner margin to 100 feet per mile along the Hwang Ho. The dip, however, subsides to half the latter amount within a few miles. It is estimated that the coals occur at depths less than 2,000 to 2,500 feet below the deeper valleys in a north-south belt averaging 10 miles in width and extending 250 miles along the west side of the river from Paotehchow to the Fen Ho. This would be equivalent to an area of 2,500 square miles in Shensi which, on the basis of a 20-foot thickness of workable coals, would afford about 58 billion tons within the depth limit indicated. Most of this would be recoverable by present methods if the price obtained should warrant the expense of mining at such depths. The entire area, except at the north and south exposures described, is below drainage level in a region where the rocks, as a result of the overlying loess "feeder," are likely to be saturated with water, all of which would have to be raised by pumping.

[6] Wang, C. C., "Stratigraphy of Paotehchow, N. W. Shansi," Bull. Geol. Surv. China, No. 4, Oct., 1922, pp. 107–118.

Coals of Central Shensi.—Under this head are included the coals of the south rim of the North Shensi Basin from the Hwang Ho to the Kansu line near Lungchow. They belong to two groups, the first including those in grabens between the fault front of the Tsin Ling-Ta-Hua ranges and the rim of the basin proper; and the second embracing the marginal coals of the basin itself.

The graben belt is about 200 miles in length, and decreases in width from 60 miles near the Hwang Ho to 30 miles near Lungchow. Theoretically, coal may be expected anywhere within this area of nearly 9,000 square miles. As a matter of fact, however, the region is not only more shattered by faulting than in Shansi, with a larger proportion of horsts from which the coals have been removed, but the average tilting is greater and the outcrops correspondingly narrower. Moreover, the entire southern part of the belt, amounting to some 5,000 square miles, has been lowered by faulting and is now covered by an unknown but great thickness of sediments deposited by the Wei Ho, as well as by the high loess terraces or plateaus on both sides of the valley of the stream named.

Inside of the rim of the basin proper, there is in Shansi a belt of coal measures lying upon the Ki-chou limestone and sloping in a normal manner toward the center of the basin. This enters Shensi from Shansi just above the mouth of the Fen Ho, and constitutes the second of the two belts mentioned. In Shensi, the coal measures are covered by great deposits of loess. So great is the thickness of the latter, that from the Hwang Ho to the Lo Ho, a distance of 50 miles, practically all beds except those in ravines close to the first-named stream are hidden from view. Even the Lo Ho, although cut 800 feet or more below the level of the loess plain, failed to reach the rock at the point at which we crossed it. Similar conditions continue to the west as far as Lungchow, although the loess is thinner locally. For this reason, it is often impossible to determine whether isolated coal outcrops are to be referred to grabens or to the North Shensi Basin.

West of the Lo Ho, the first exposure of the coal measures noted was 25 miles southeast of Ichun, where flat-lying beds of

dark shales were seen in association with greenish sandstones. Coal was reported in the vicinity.

The next exposures to the west were seen on the cart road between Yaochow and Tungkwanhsien. The Shan-si beds, with several coal mines, occur on a downthrown fault block between uplifted blocks of Ki-chou limestone about 7 miles south of the last named city and about 50 miles north of Sianfu. Similar beds, also with mines, are found above the Ki-chou limestone at the northwest exposure of the latter 3 to 4 miles south of Tungkwanhsien. A third and very narrow outcrop, apparently brought up by faults between masses of the Pu-hsien formation, is found just north of the latter city. The southern outcrop has a width of 2 miles, the middle 3 miles, and the northern about 1 mile. The formation is much more sandy than in Shansi, with coarse, often cross-bedded greenish sandstones predominating over the shales, which are usually weakly developed. The coals are said to be friable and dirty. Their aggregate thickness is unknown, but the total of workable beds is not likely to exceed 10 or 15 feet.

Green sandstones of what is supposed to be the Shan-si formation were noted in unusual thickness for 6 miles along a stream bed, 15 to 20 miles northwest of Sanyuen, but no coals were seen or reported. Similar sandstones were observed 20 miles northwest of the last locality, but again no coals were noted. The same is true of a small showing of sandstones in the valley immediately north of Yungshou. Southwestward from Linyu, beds of similar character were seen in 1,000-foot ravines cut at intervals through the loess for 20 miles, but again no coals were observed. Massive green sandstone and conglomerate (Shan-si?) without coals occur 15 miles northwest of Fengsiangfu.

The most southwesterly point at which the Shan-si series was noted was near Lungchow near the Kansu line, where green sandstone with shale and coals, some of which are mined on a small scale, are exposed in the bed of the Kienshui, 5 miles southeast of the city, thence along the river for 8 miles farther in the same direction. At the northwesterly exposures the dips are 1°–3° to the northwest; but in the central (coal bearing) and southeasterly

exposures they range from 25° to 45°, or even up to 90° at one point. The great disturbance points to a probable proximity to the south margin of the basin, although nothing was seen of the Ki-chou limestone.

While, as has been seen, the area between the mountains south of the Wei Ho and the normal outcrops of the North Shensi Basin, all of which may be considered as possible coal territory, measures nearly 9,000 square miles, the area in which coals will be recoverable will be relatively small, not less than 5,000 square miles being rendered inaccessible because of the enormous covering of loess or the alluvial filling above the downthrown block of the Wei Ho valley. If the proportion of grabens to horsts is approximately the same as in Shansi, the remaining 4,000 square miles may be expected to afford only about 2,000 square miles of territory actually underlain by coal measures.

Within the limits of the North Shensi Basin itself the dips are high, frequently from 3° to 10°, and the outcrop of the formation is narrow or cut out by faults. The coals appear to be carried to great depths within a comparatively short distance. Ten miles is regarded as a probable average limit of availability. This would be equivalent to an area of 2,000 square miles in the 200-mile interval between the Hwang Ho and the Kansu line.

Combining normal outcrop and graben areas of central Shensi, we arrive at a total of 4,000 square miles of territory in which the coal may be recoverable, although it is doubtful if all of this will ever be mined.

Very little is known of the thickness of the coals as a whole. The total thickness of the workable coals, judging from the infrequency of "blossoms" as compared with Shansi, is probably not more than half the 20 feet assumed for the last mentioned province. On the basis of 10 feet of recoverable coal over the 4,000 square miles mentioned, the available tonnage would be about 47 billion tons. Although both thickness and area of accessibility may be greater than assumed, the conditions of cover are such that it is not believed that the recoverable tonnage will be much larger than the above estimate, and it may be considerably smaller.

Coals of East Kansu.—These are the coals near the west rim of the North Shensi Basin. The region is one of deep loess and was crossed only (1) at Lungchow, Shensi, just south of the Kansu-Shensi line, (2) 25 miles southeast of Lingchow in northeast Kansu, and (3) 20 miles east of the same city. The Clark expedition, which reached the west edge of the basin near Kuyuanchow, Kansu, in 1908–9, reported limestone, but did not mention coal.[7] The fact that coals were elsewhere recorded whenever encountered suggests that they are either absent or buried by loess at this part of the basin rim.

The coals near Lungchow have been mentioned in connection with the discussion of central Shensi. At the locality 20 miles east of Lingchow in northeast Kansu, coarse green sandstone, limestone and coal outcrop for a breadth of 10 miles on a bench several hundred feet above and 10 miles east of the valley-plains of the Hwang Ho. The sandstone is similar to that of the south rim of the basin and shows dips of 10 to 15°. The limestone is 20 to 30 feet in thickness, while we were told that the coals have a thickness of 2 to 3 feet. Their actual thickness may, however, be considerably more in places. Many pits and some old mines were noted, but none seemed to be working at the time of our visit. A coal reported as from Ningshia but probably from here is described by A. C. Sowerby[8] as heavy and dirty, but smokeless, continuing to burn, when once ignited, with a dull glow, smouldering like charcoal, until reduced to a soft white ash. The coal, the description of which suggests an athracite, has at times been rather widely distributed by mule trains throughout northeast Kansu and north Shensi.

The third locality is 25 miles south and 2 to 8 miles east of Lingchow, and about 30 miles southwest of the exposures described in the preceding paragraph. The coal measures were seen mainly along a valley cutting into a bench standing several hundred feet above the Hwang Ho plains. The beds out-crop, probably with some repetition, for a distance of over 15 miles.

[7] "Through Shen-Kan," R. C. Clark and A. C. Sowerby, London, 1912. Geological Notes, pp. 115–129.

[8] "Through Shen-Kan," p. 123.

They are strongly folded, with dips up to 60°, and are probably much faulted. There are some shales, a hard-white bed (fireclay?), some limestone, and at least one coal, reported from 2 to 5 feet thick and said to be worked locally.

The data for estimating the tonnage of the coals on the west side of the North Shensi Basin are, as has been seen, very meager. Where crossed, the available thickness of the combined beds was probably not over 10 feet. Even at the outcrop, the folding and faulting is such as to make the determination of area impossible except by long and careful work. To the south of the Lingchow region, the coal measures are mostly deeply buried beneath hundreds of feet of loess. On the assumption of a 10-foot thickness, a 5-mile width of available outcrop, and a distance of 250 miles from the Mongolia line to the Shensi boundary north of Lungchow, the probable productive area would be 1,250 square miles and the available coal less than 15 billion tons.

Ordos Region.—In the absence of any definite knowledge of the coals of the north rim of the North Shensi Basin we can make only the merest guess as to the tonnage. We are inclined to assume that the total thickness of the coals present will be less than on the Shansi side of the Basin but more than on the Kansu side, but have assumed 10 feet as the amount recoverable. The absence of the immense thicknesses of loess, although in part counterbalanced by broad belts of drifting dune sand and large areas of gravel wash, will tend to make a broader area of coal available than on the south or west sides of the basin, but the high dips and severe faulting will tend to reduce the available area. It is thought that the coal may be recoverable beneath a belt 10 miles wide and 350 miles long between the point where the rim leaves Kansu near Ningshia and its return into Shensi at the northeastern corner of the province (Fig. 1), a total of 3,500 square miles. On the basis of a 10-foot thickness, the tonnage recoverable would be about 41 billion tons.

Total Permo-Mesozoic Tonnage.—The estimated available tonnages for the east side of the North Shensi Basin, including grabens, has been given as 210 billion tons east of the Hwang Ho

and 58 billion west of that river, that of the south side of the basin as 47 billion, that of the west as 15 billion, and that of the north as 41 billion, making a grand total of 289 billion tons as the probable available coal around the rim of the basin.

Since the coals occur on all sides of the North Shensi Basin in similar relations to the rim, it is assumed that they underlie the entire trough, with an area of some 100,000 square miles, including grabens. Assuming the average thickness of the Permo-Mesozoic coals to be 15 feet over the entire basin, we arrive at a total tonnage of 1,750 billion tons, of which it is probable, allowing for varying thicknesses, some 150 billion tons are in Shansi, 664 billion in Shensi, 295 billion in Kansu, and 581 billion in the Ordos. The greater part lies beneath from 3,000 to 10,000 feet of Jurassic sediments, to which must be added from 500 to nearly 2,000 feet of loess.

JURASSIC COALS.

The Jurassic coals, so far as workable beds are concerned, occur somewhat above the middle of the Shen-si formation. In northern Shensi, this formation is divided into three sections which are termed phases rather than formations because of the lack of any persistent lithological characteristics which might be used to fix their limits throughout the basin. The phases from top downward are as follows:

Phases of Shensi Formation.

	Thickness (feet).
Tientou Phase: Top of gray to red sandstone; lower parts of thin gray shales and sandstones	1,500
Yenanfu Phase: Massive sandstones at top and bottom with shales and coals in middle	1,000
Yenchang Phase: Predominantly hard gray thin-bedded sandstones	3,500

The coals occur above the middle of the Yenanfu phase some 4,000 feet above the base of the Shensi formation.

The coal belt enters Shensi just east of Yulinfu, and extends

[9] Thicknesses are maximum in Yenchang-Yenanfu districts. Farther south they are considerably less.

southward, passing east of Wangyaopu, Yenanfu and Fuchow, thence bends eastward to Tientou, beyond which it disappears beneath the overlapping late Jurassic formations (Fig. 2).

There seem to be at least four coals of some persistency, but in general there were only two of sufficient thickness to warrant mining. Whether or not they are the same pair in all localities is difficult to determine, as many miles of loess covered territory usually intervene between the exposures. Each coal was stated to be from 2 to 3 feet in thickness, but either may thicken to 4 or 5 feet in places, while elsewhere it may thin out to a few inches. Local pockets of much greater thickness probably occur. The coals are described as dirty, bituminous types, with much slate in the thicker beds. The coal gives much smoke and the percentage of ash is frequently high. A bed of "lignite" was reported near Anting, but it is probably a soft bituminous coal.

An analysis of coal, presumably from the main workable bed at Kuitepu shows the following percentages: Moisture, 5.94; volatile matter, 31.83; fixed carbon, 60.15; ash (brownish gray), 208; sulphur, .49. It is a coking coal.[10]

The following table summarizes the outcrops and workings which came to our attention:

SUMMARY OF JURASSIC COALS.

(Principal mines and outcrops are shown by crosses on Fig. 2.)

Locality.	Situation.	Nature of Exposures.
Yulinfu	(1) 4–5 miles east	Coal pits
	(2) 10 miles east	Outcrops
Kueitepu	(10 miles south of Yulinfu)	
	(1) north of city	Shaft mines (?)
	(2) south of city	Shaft mine
Yuhomao	(20 miles southeast of Kueitepu)	Reported mine (small)
Wangyaopu	(45 miles southwest of Suitehchow)	
	(1) 4 miles west on Anting Road	Mine
	(2) 10 miles north	Two or more mines and several pits along creek

[10] Wang, C. C., "Stratigraphy of North Shensi," *Bull. Geol. Soc. of China*, vol. 4, Pt. 1, pp. 57–67, 1925.

	(3) 2 miles southwest	Coal and "bentonite"
	(4) 15 miles south	Outcrops
	(5) 17 miles south	Outcrops
	(6) 19 miles south	Outcrops
	(7) 6 miles east	Mine
	(8) 8 miles southeast	Outcrop
	(9) 15 miles southeast	Mines reported
	Coal No. 1 belongs to highest horizon, Nos. 2–6 to middle horizon Nos. 7 and 8 to lowest horizon. No. 9 report is too indefinite for assignment. Intervals were not worked out.	
Yenanfu	10 miles northeast	Mines and outcrops (probably two horizons)
Fuchow	(1) 5 miles northeast	Coal workings
	(2) 10 miles northeast	Coal mine
	(Probably same as Yenanfu)	
Tientou	(11 miles west of Chungpu)	Two coals, 100 feet apart, mined near town. Probably same as those near Fuchow.

The so-called mines are usually shallow pits or tunnels of no great length, but shafts have been sunk to the coals in places between Yulinfu and Yenanfu. All labor is done by hand, and even the water, when encountered where it cannot be removed by natural drainage, being carried out in buckets. The amounts mined are relatively small and are transported to the nearest villages and cities by mules.

Thickness of Coals.—As elsewhere, it is very hard to determine the average thickness. One may cross the coal horizon in places without seeing any indications of coal whatsoever. Elsewhere the seams are of considerable thickness and actively mined. Five feet is a probable minimum and 12 or 15 feet a possible maximum thickness of workable coal. An average of 10 feet is adopted for the purpose of the present estimates.

Area of Coals.—The outcrop from the Great Wall to Tientou,

where the coals apparently go under the later Jurassic, which rests disconformably upon the Shen-si formation, is about 225 miles in length. The dip averages about 50 feet per miles to the west, carrying the coals 1,000 feet downward in 20 miles, but to the normal rock cover must be added 500 feet or more of loess everywhere except in the valleys. Considerable areas, however, occur in the hills above drainage. By combined surface and shaft workings, the coals, if the thickness of the individual beds warranted, would be recoverable by modern methods throughout a belt not less than 20 miles wide. This would be equivalent to an area of 4,500 square miles, and on the basis of a 10-foot thickness would yield over 53 billion tons of coal in Shensi. Assuming that the coals extend across the Ordos to the vicinity of the north rim of the basin and westward beneath the later formations to or beyond the region of Kiangyangfu in Kansu, the total area of the Jurassic coals will be roughly 30,000 square miles and the tonnage, practically non-recoverable, probably not less than 350 billion tons on the 10-foot basis. Of this Shensi, Kansu, and Mongolia each have about a third, or about 117 billion tons each. The area of recoverable coals in the Ordos is about 2,500 square miles, which should yield about 30 billion tons.

SUMMARY OF COAL TONNAGE.

The total recoverable tonnages of the coals of the North Shensi Basin are summarized in the table below. Under recoverable coal is included that which is not beyond the depth of practicable mining, although much of it will probably never be actually removed from the ground. The non-recoverable coal is that which will not warrant removal under normal conditions, although much could be recovered if its value warranted unusually deep mining. The term Basin in the first column refers to the North Shensi Basin. All figures are in tons of 2,000 pounds each, and are necessarily merely approximations.

It is frankly admitted that many factors are incompletely known, this being especially true of the thicknesses, which vary widely from place to place and are seldom definitely known even

SUMMARY OF COALS IN NORTH SHENSI BASIN AND ADJOINING GRABENS.

Province.	Permo-Carboniferous Coals.				Jurassic Coals.				Total Coals (Overlapping).	
	Recoverable.		Non-recoverable.		Recoverable.		Non-recoverable.			
	Area (Sq. m.).	Tons (Billions).	Area (Sq. m.).	Tons (Billions).	Area (Sq. m.).	Tons (Billions).	Area (Sq. m.).	Tons (Billions).	Area (Sq. m.).	Tons (Billions).
Shansi										
Basin.....	5,600	128	0	0	0	0	0	0	9,000	210
Graben.....	3,400	82	0	0	0	0	0	0		
Shensi										
Basin.....					4,500	53	5,500	64		
East.....	2,500	58	29,500 (whole basin)	560					36,000	781
South.....	2,000	23								
Graben										
South.....	2,000	23	0	0	0	0	0	0		
Kansu.....	1,250	15	22,750	280	0	0	10,000	117	24,000	412
Mongolia.....	3,500	41	27,500	540	2,500	30	7,500	86	31,000	697
Totals....	20,250	370	79,750	1,380	7,000	83	23,000	267	100,000	2,100

at a single point. The heavy cover of loess enters materially into the problems of area, preventing the determination of the limits of the graben "basins" as well as modifying the extent of recoverable areas. While thousands of miles of traverses were run within the 100,000 square miles of the basin, there are several comparatively broad stretches of unvisited territory, some being as much as 50 miles in width. Of these, there are no available maps except of the most general type, and conditions can only be judged by inference. The various factors entering into our estimates have been stated, and comparisons may be readily made as new facts come to light in the future.

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EDITORIAL

PRIMARY CONCEPTIONS IN ORE-GEOLOGY.

WHILE the Victorian idea of science assumed that the iron laws of nature had already been discovered, and that all there was left to do was to fill in the details, the present-day attitude seems altogether different; for scientists are beginning to convince themselves that laws are merely convenient descriptive formulæ for correlating scattered phenomena, and that, furthermore, even in that sense, they rest on primary conceptions which have not been verified. Such conceptions, if we only go far enough back, are found to lie behind each branch of science. We have made a choice among alternatives to begin with; that choice becomes a part of our method; and thereafter, out of any set of many observations, we have picked those for emphasis and development which seem best to agree with what we consider "common sense;" and now this "common sense" turns out after all to be merely the sense of security and assurance which comes from conceptions firmly fixed.

The real nature of this sense of security and assurance is illustrated by the history of the notions on the shape of the earth. Not so long ago, common sense dictated to the earth-dweller that the earth is flat. Accumulating evidence at length began to point at reasons for the belief that it is round. That idea was finally accepted by all. Yet that it must have caused a shock is readily realized from the trouble that immature or untrained people still have in explaining how the men of the Antipodes stick to the under surface without falling off, and how they walk about with their heads downward. It is despite this trouble that this idea, once incomprehensible, has by constant repetition become a matter-of-fact, every-day conception. Common sense, despite its

appearance of stability and its much-praised importance, is constantly undergoing correction and change. The common sense views of this generation differ from those of the past; those of the next will inevitably differ, we may be certain, from those which we now hold. It is the essence of scientific effort that its discoveries should constantly make over its assumptions, and that they should gradually enter into and modify the sense of the world. Science, and with it the ideas of common men, is constantly starting again at a new place, and adopting a new course.

In ore-geology, as everywhere else, we begin with some conception or other. For example, no matter what we do or think toward clarifying our thoughts on the origins of ore, in the backgrounds of our minds most of us have the idea that the metals have come directly from igneous magma. We may dispute the mechanism of transportation, or the concentration of the solutions, or the temperature at which various minerals are made, but the source in general we do not dispute. But let us, for the sake of illustration, once assume that the idea is radically erroneous, and, transferring all our reasoning to some other source, we get an entirely new picture of ore-geology; just as, by transferring the center of the universe to some point outside the earth, the inquirers of past centuries established an entirely new astronomy.

This undermining of an old idea would seem little more than idle speculation. What could be clearer, what could be simpler or more convenient, than this basic conception of ore origin? Yet what, in reality, do we know about the derivation of the metals? Sulphide mineralization is assuredly a function of igneous intrusion, for we find the two occurring together. But what kind of a function? Did the magma emit the metals, or did it only serve to collect them? Was it an actual source? Or did it only provide the heat, or the fractures, or the water, which made possible the concentration of metals drawn from some other place? Who has traced a metal back to its origin? And why, after all, this immediate confidence that this special association, leading from that body of intrusive to this body of ore, is in reality the correct one? Is it so certain that other associations are not possible?

Indeed, other associations are possible, for the Mississippi Valley ore deposits are generally thought to be concentrations of metals once widely scattered through the sedimentary rocks, despite the fact that they closely resemble deposits in other parts of the country which are believed to have had a direct igneous origin. What do these opposed ideas mean? Which is the rule and which is the exception? Or, is there any rule at all? When two sets of facts look away from each other, what are we to do about it?

We simply choose between them. We choose one thing and let something else go. It is always so. Out of all the possible directions we have to choose one if we are to move. And, as the choice is made, the direction of all further progress is governed. Moreover, the decisive factor in the choice between opposite courses may be trivial, or vague, or imponderable, just as, at the beginning of an erosion cycle, the direction of the first stream of water may be turned by a pebble. And, once the beginning is made, a whole configuration of valleys, gorges, canyons, and mountains is determined where otherwise there might have been something else.

This all means merely that the degree to which assumption enters into the reasoning has to be constantly taken into account. There is danger that instead of being used as mere hypothesis, which will assist inquiry, a conception will gain the standing of an axiom, which will serve to bring the inquiry to an end; and that, while the derived ideas may be the subject of intense activity and experiment, the conception itself will lie so deeply hidden that the science will possess the dogmatic characteristics which are assumed to be apart from its nature. There is, for example, an overwhelming tendency to select and perpetuate the simple explanation, although there is an increasing conviction that the simple does not represent the nature of the universe.

Deeply impressed primary conceptions, then, are the beginning of all our work. And we have to remember that these conceptions may vary all the way from a tested principle to a mere belief set up by repeated iteration, and that the sense of security with which they are accepted is no necessary measure of their intrinsic value.

To what degree are we aware of these primary conceptions in ore geology? Is their nature being estimated and is their valuation being duly revised as new facts become available? There are, of course, a number of primary conceptions in ore geology beside the one which has been mentioned; for example: that of the zoning of metals around an intrusive source; that of the subdivision of the minerals into temperature groups; that of a distinct kind of "shallow vein" deposits; and that of a sharp discontinuity, instead of a gradual transition, between the kinds of supergene and hypogene ores. It is these and others like them that make the actual basis from which we start to think about ore deposits, and we may say that it is an outstanding quality of ore-geology that its primary conceptions are remarkably persistent.

Although these ideas all seem reasonable, it is well to reflect that the history of science and its present movement show reasonable ideas of this very kind often to have led men astray. Let us not forget the confidence with which we still so recently believed that matter is indestructible; that the atom is not divisible; that matter and energy are separate entities; that energy is infinitely divisible; and that light travels only in straight lines. And let us not forget the widespread stirrings and readjustments which have followed our liberation from these ideas, the vistas which have been opened up, and the results which have come after.

When so many sacred tenets of other sciences are crumbling away, why do ours remain so long untouched? Do they by some accident happen to be truths that can stand up like mountains when everything is breaking around them? Or, is not their very stability in the midst of such change a reason for suspicion? Does it not, perhaps, signify that, without knowing it, we have become prisoners in the habits of our own thoughts?

Indeed we cannot help realizing that, even to-day, every new controversy regarding ore formation is confined within boundaries that have been long established, and that there almost seems a tacit understanding that these boundaries shall not be broken through. Are we not trying to put things together which will

not go together after all? May it not be that these ideas are indeed standing as huge and invisible obstacles repeatedly turning us aside and confining our thoughts within a circle? May it not be that our primary conceptions, fundamental as they are, constitute the very reasons why our present-day ore-geology is so slow to move? And that their reconstruction will leave us free to go forward on that journey of progress which we have so long been expecting to start?

AUGUSTUS LOCKE.

JAMES FURMAN KEMP.

TO HIS MEMORY.

THE brief announcement in the December number of the death of James Furman Kemp, on November 17, brought sorrow to a circle of friends and colleagues scattered far and wide over the earth. Across the seven seas the message was carried to the seats of learning and to the lonely mines of the engineer. Few men, it may be truthfully said, ever had a larger circle of devoted friends and few have deserved this blessing as Kemp did.

And science grieves no less, for with his kindly spirit passed a great investigator, a great teacher in his chosen field, a man who has left his indelible mark on the science of geology. To fully record his work can not be attempted in these lines, but it is fitting that we should here specially recall what Kemp has done and what he meant to the fortunes of the journal of ECONOMIC GEOLOGY. Turn to the first issue in 1905, and you will find his name as our associate editor on the front page, and a fundamental paper of Kemp is contained in that number. Turn to the last number: you will find him still as an associate editor and one of his editorials appears in the November issue, the very month of his death.

Between these lie twenty-one volumes, twenty-one years during which he gave fully and freely of his great store of knowledge to the advancement of science. Whenever, especially in the early

and more difficult years of the journal, there was needed some interesting material, some stirring discussion, Kemp could always be relied upon to help us out. Gratefully, we acknowledge this great debt; no one will ever just fill his place.

James Furman Kemp was born on August 14, 1859, in New York, of a line of Scotch and English forebears. He graduated from Amherst with the degree of A.B. in 1881. From Amherst he came to the School of Mines, Columbia University, where he received the degree of Engineer of Mines with the class of 1884. After graduate study in Munich and Leipzig, he became instructor in Geology at Cornell University in 1886, assistant professor in 1888. In 1891, he was called to Columbia University as adjunct professor and in 1892 on the death of J. D. Newberry, he became professor and in charge of the department. In this position he remained until his last day. On November 17th as he was about to board the train at Great Neck for his daily duties at the University he passed away suddenly from a heart attack. Only thirty-six hours previously he had been the speaker of the evening at a largely attended meeting of the New York Section of the American Institute of Mining and Metallurgical Engineers, at which he gave an interesting account of the mines in Spain which he had visited during the previous summer. Thus passed James Furman Kemp: A life to be envied, a death to be desired.

Of his many honors, I shall speak briefly: In 1905 Amherst conferred upon him the degree of honorary Sc.D.; in 1913 McGill University gave him the degree of LL.D. He was a member of the National Academy of Sciences; the Geological Society of America (President 1921); the American Institute of Mining and Metallurgical Engineers (President 1912; honorary member 1914); the Mining and Metallurgical Society (President 1912, honorary member 1917; gold medal 1916); the New York Academy of Sciences (President 1905 and 1910); and of many other societies. Also, he was a corresponding member of the Geological Society of Stockholm, of the Academy of Science of Kristiania and of the Geological Society of London.

In 1889, Kemp married Kate Taylor of Kingston, R. I., a

most happy union; there were three children, now grown up, who with their mother are left to mourn the too early passing away of an ideal husband and father. A few years ago the Kemps moved out to more pleasant surroundings near Great Neck, Long Island. Whoever has had the opportunity to spend a week-end at their home, or the delightful chance to travel with Mr. and Mrs. Kemp will never forget the hospitality extended and the cheer that emanated from this happy family. With great apparent strength Kemp suffered once or twice from a nervous breakdown, undoubtedly brought about by too hard and constant application to work. About ten years ago he recovered, his friends hoped fully, from such an illness, by living out of doors on the beaches of Florida.

The scientific activities of Kemp were so extensive and covered so many fields that it is not easy to summarize them briefly. But before entering on this subject it is proper to mention his unusual and wonderful qualifications as a teacher. Preëminently Kemp was a teacher; a teacher rarely surpassed in his ability to inspire his students with love for science; a magnetic personality which caused young men to love him with devotion almost from his first appearance in the lecture room; a most interesting lecturer, never dry and impersonal; and with an ability to pick out research problems, to guide the student, to impress him with the value and necessity of accurate work. It is not likely that we shall soon again see a teacher so universally beloved, a leader of such ability. And how these students liked to come back and meet their old instructor and discuss their problems with him! In point of fact the time which he ungrudgingly took for this purpose was a heavy draft on his strength—together with all the other duties of a professor of one of the largest universities in the United States.

His sense of humor was keen; he was easily the center of any convivial meeting. Few of us will ever forget some of his droll, impromptu sketches. I refer particularly to his inimitable discussion of "The Geology of Jell."

His first paper recorded is a description of the geology of the Island of Manhattan, published in the *Transactions* of the New

York Academy of Sciences in 1887. In his earlier work much attention was given to petrography and in this he was influenced by the association with his teacher John Francis Williams. Many of his papers deal with interesting types of dike rocks in Arkansas, New York, Maine and Pennsylvania; another later paper describes the most unusual rocks of the Leucite Hills, Wyoming. Throughout his life Kemp was a distinguished student of petrography, but he was really more concerned with its application to economic geology than as a separate subject.

In 1896, Kemp published "A Handbook of Rocks for Use without the Microscope," which proved a wonderful help to students. Its popularity is indicated by the fact that it went through five editions, the latest in 1911.

As early as 1887, Kemp made his first investigation along this line of applied geology which was to become the major feature of his work. The subject was the ore deposits of southeastern Missouri, and the concentration of these ores. Soon after, while at Cornell, he conceived the idea of a book descriptive of the ore deposits of the United States. This celebrated work, which was destined to go through five editions, was published in 1893, and it established his reputation on a firm basis. One of the most useful books and most timely, it met with a cordial reception as the only standard work of its kind. Later followed in rapid succession papers on the Franklin Furnace deposits, the nickel mine of Lancaster Gap, the titaniferous iron ores of the Adirondacks, the Ducktown copper deposits and many other ore deposits.

Kemp had always been much interested in the occurrence and mineralogy of platinum. In 1902, he admirably summarized his studies in Bulletin 193, U. S. Geological Survey.

We now come to another important phase of Kemp's studies. From 1890 on he took up the study of the geology of the Adirondacks, both in a general way and connected with ore deposits. For many years, off and on, this work occupied much of his time and the results were published in the Annual Reports and Bulletins of the State Geologist of New York and elsewhere. In part this work was done in conjunction with D. H. Newlands.

Too much can not be said in commendation of Kemp's labors in this field. He established the geology of the complex region in a way that will serve as a foundation for all coming efforts, and he correctly and with wonderful insight outlined the genesis of the magnetites and the titaniferous iron ores of that region at a time when an igneous origin of ores was still sharply contested.

About 1902, a new trend may be observed in Kemp's activities. He began to devote himself more definitely to the theory of ore deposits, to their origin and relationships, and to some extent this trend is traceable to the stimulating work of Professor Vogt on the relations of volcanism to the development of ore deposits.

The first paper of this period was entitled "The Rôle of the Igneous Rocks in the Formation of Veins," (*Trans. Am. Inst. Min. Eng.*, 1902, reprinted in Posepny Volume of 1912), a fundamental paper, probably the first in this country which definitely linked igneous rocks with many kinds of ore deposits and which involved Kemp in a controversy with Van Hise. It was followed by a second paper on "Igneous Rocks and Circulating Waters as Factors in Ore Deposition" (*Trans.*, 1903, reprinted in Emmons' Volume of 1913). In 1905, the first number of ECONOMIC GEOLOGY appeared. Kemp was one of the small group of geologists who created this new medium and J. D. Irving, one of Kemp's students, was the editor of the journal. Kemp's pen contributed largely to the first volume, and indeed to all subsequent volumes. New viewpoints were discussed by Kemp in "The Problem of the Metalliferous Veins"; "What is a Fissure Vein?"; and "Secondary Enrichment in Ore Deposits of Copper," all in the first volume. His work in this direction found further expression in the discussion of "Ore Deposits at the Contacts of Intrusive Rocks and Limestone" (in volume 2, ECON. GEOL., and in the *Compte Rendu of the Internat. Geol. Congress in Mexico*, 1906), in the paper on "Ground Waters" (*Trans. Am. Inst. Min. and Met. Eng.*, 1913) and the "Influence of Depth on the Character of Metalliferous Deposits (*Internat. Geol. Congress*, 1913). This line of investigations culminated in his presidential address to the Geological Society of

America in 1921 on the "After Effects of Igneous Intrusion." The importance and value of these investigations can not be too strongly emphasized.

Many investigations on mining districts filled in the time between these papers. Specially notable was his work on the copper deposit of San Jose, Tamaulipas, Mexico (*Trans. Am. Inst. Min. Eng.*, 1906) in which the replacement of limestone by andradite and the active metasomatism in contact metamorphic deposits was first described. "The White Knob Copper Deposit at Mackay, Idaho" (*Trans. Am. Inst. Min. Eng.*, 1907) was an important study on the same subject, as was the paper on Daiquiri, Cuba (*Trans.*, 1916), and that on Gold Hill, Utah (ECON. GEOL., 1918). Quite a different field was represented in Kemp's valuable paper on the Mayari iron ores of Cuba, and the comprehensive report on the Iron Ore Reserves in the United States, and in Central America, the latter two investigations published by the International Geological Congress in Stockholm in 1910.

There are other lines of Kemp's work which can only be touched on briefly in this place. Perhaps the most important is his physiographic investigations in connection with the New York Water Supply, embodied in papers on the Catskill aqueduct. Besides his manifold duties and scientific work Kemp also found time for examinations for many of the most prominent mining companies of the country; his advice, always sound, was highly valued.

The mere account of work achieved, however important, leaves us without the key to the spirit of the man. The personality of Kemp, overshadowing everything, takes on an importance even greater than scientific results. Kemp's genial kindness, his gentleness and his generosity were his most conspicuous characteristics. A teacher for forty years, he delighted in the instruction of his students and set an example for them in the life worth living. Professor Berkey puts it well when he says that "Professor Kemp had a rare combination of kindliness and serious concern, coupled with a never failing buoyancy and humor. . . . His lectures were marked by literary skill; his sentences always fell

with smoothness and grace; he was never in want of the right word. . . . He was always in demand as a speaker, as a member of committees and delegations of all kinds. . . . His brilliant wit and elegant form of expression and ready tact made him especially acceptable on many important occasions."

And thus passed, all too early, one of the most distinguished and widely known geologists of his day—a man of wonderful personal qualities, one of the most beloved of all teachers. Long shall he live in the memory of his friends, and forever in his work.

WALDEMAR LINDGREN.

DISCUSSION AND INFORMAL COMMUNICATIONS

EARTH TEMPERATURES, BURIED HILLS AND ANTICLINAL FOLDS.

Sir: Having read the discussion of my paper on the "Relation of Earth Temperatures to Buried Hills and Anticlinal Folds," presented by Chester W. Washburne in the June–July, 1926, issue of ECONOMIC GEOLOGY, I believe it is desirable to present some of the evidence, previously omitted for the sake of brevity, upon which my conclusions were based.

As Mr. Washburne suggested in the article cited, the movement of ground waters may cause a transfer of heat from synclinal areas into adjacent anticlinal uplifts, as is well illustrated in the Grosny fields of Russia, and it is impossible to estimate with precision how much the earth temperature conditions in any area have been modified by such migration. It is nevertheless the writer's opinion that fluid effects are incidental rather than primary factors in causing the existing distributions of earth heat, and that there should be, and is, a more or less definite relation between earth structure, and earth temperatures and temperature gradients. Mr. Washburne's principal difficulty seemed to be that he could not accept the idea that an Eocene uplift of isogeotherms can still be recognized. To the writer, whose opinions are largely colored by conference with Dr. C. E. Van Orstrand of the Geological Survey's geophysical staff, it seems that such an uplift, like the proverbial variable, will approach extinction as a limit, but will never reach it, and in view of the facts that principal cooling effects take place very close to the earth's surface, and that erosion at Salt Creek has progressively lowered the surface to an aggregate amount of some two miles (thus continually removing the cooled layers and exposing the relatively

warm ones beneath) it seems no surprising matter that very perceptible evidences of the Eocene uplift of isogeotherms should still persist, and furthermore, according to Dr. Van Orstrand's calculation 29 per cent. of the initial arching of isogeotherms caused by anticlinal folding would still persist at a depth of 2 miles after 100,000,000 years.

One is not, however, limited to grounds of theory in the present instance, for the quantitative data now available, on the one hand, rule out circulating hot waters as the important cause of earth temperature conditions in the Wyoming anticlines mentioned by Mr. Washburne, and on the other hand affirm that there is a systematic agreement between earth temperature and earth structure.

That the Salt Creek dome is not being heated by artesian waters migrating from the southern end of the Powder River geosyncline beneath the Salt Creek field is demonstrated by the following facts:

(1) The First and Second Wall Creek sands and the Lakota sand contain oil beneath the higher part of the Salt Creek dome, and hence heating by water circulation in these sands, according to Mr. Washburne's theory, should take place around the margins of the dome, rather than near its crest, whereas actually the coldest wells measured were the marginal ones in or near the edgewater zone. Moreover the typical " depth " temperature curve for these marginal wells shows an inflection near the bottom end which Doctor Van Orstrand regards as indicating that the water-bearing sands are not sources of excess heat.

(2) Some oil has been found in Morrison and Sundance sands beneath the higher part of the Salt Creek dome and a small oil pool may also exist in the Tensleep sand, thus seriously curtailing and perhaps eliminating the possibility that important volumes of hot waters are passing beneath the apex of the uplift. Furthermore, the well drilled to the Tensleep in the SW ¼ sec. 25, T. 40 N, R. 79 W, obtained large flows of water from it at depths between 4,120 and 4,337 feet, having well mouth temperatures (according to the Midwest Refining Co.) ranging, respectively, from 167° F. to 174° F. These casing head temperatures are presumably somewhat lower than the sand temperatures, due to

gas expansion and other causes, but, making every reasonable allowance for such possible differences, it appears that the Tensleep water is not abnormally hot for the depth at which it occurs and that it has no potency as a heating agent.

(3) A regional quantitative study and compilation of the structure of northern and northeastern Wyoming was carried out by the writer and was used by him in arriving at the conclusions now brought into question. From this map, sand distribution and outcrop elevations being duly considered, it is evident that Mr. Washburne's hypothesis as to directions of water movement and loci of water discharge involves unreasonable and even impossible assumptions as to hydraulic head and gradient relationships and calls for large water discharges in areas where no such discharges can be demonstrated. He also confuses water circulation conditions in the Wall Creek sands of the Salt Creek area (which are foreign to the problem, because these sands contain stagnant oil, not moving water, beneath the Salt Creek dome) with circulation conditions in the Dakota-Lakota, Sundance, and Tensleep sands, which, unlike the Wall Creek sands, extend northward into Montana, as well as eastward beyond the Black Hills, and it is upon these lower sands that Mr. Washburne must rely for the workability of his hypothesis. If his hypothesis is correct, waters which enter these lower sands around the Casper Mountains and descend into the Powder River basin, instead of following a contour line around the periphery of the basin toward its low northern end, rise up the dip, flow beneath Salt Creek, and discharge from outcrops near Powder River which occur at altitudes almost as great as those near the Casper Mountains. When the hydraulic gradient involved in this movement is calculated it seems obvious that no such discharge would take place against the hydraulic head of water entering the outcrops near Powder River, but rather that the inflow from both outcrops would be in general northeastward toward the low point in the rim of the Powder River basin, which is a little southwest of Miles City, Mont., and is (on Dakota datum) more than 7,000 feet lower than the Powder River outcrops. Similar objections can

be raised to Mr. Washburne's suggestions regarding Big Horn Basin water circulation.

Therefore, because actual observations in the Salt Creek field show that conditions there are just the reverse of those called for by the hot water hypothesis, and because regional structural studies similarly cast doubts upon the potency of hot waters to cause the temperature distribution in the other domes mentioned by Mr. Washburne, the writer excluded water circulation as a major factor in causing present temperature relationships in Wyoming anticlines. That such relationships are functions of cooling as related to structure is moreover confirmed by observations made by Jones,[a] in the Welsh coal fields, which show that the increase of earth temperature with depth is more rapid beneath anticlines than beneath synclines, and that earth temperatures otherwise are more or less direct reflections of geologic structure.

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SUCCESSIVE BANDING AROUND ROCK FRAGMENTS IN VEINS.

Sir: Mr. J. E. Spurr in his recent interesting contribution under the above title in your issue of September, 1926, states that banded structure "has not been sufficiently and thoughtfully studied." As a matter of fact, the general phenomena involved in banded or concentric structures have received a good deal of attention from geologists. To quote only those references of more recent date which come to mind without search of the literature, Knopf [1] under the title "Wood Tin in the Tertiary Rhyolites of Northern Nevada" has very clearly described a repeated banding of opal, hematite and wood tin. Van der Veen [2] has

[a] Jones, T. David, "Geological Disturbances and Their Effect on Strata Temperature," *Proc. So. Wales Inst. of Eng.*, vol. 41, No. 2, pp. 141–155, Apr. 23, 1925; "Further Investigations of Strata Temperatures in the South Wales Coal Field," *idem.*, vol. 41, No. 2, pp. 157–169, Apr. 23, 1925.

[1] A. Knopf, ECON. GEOL., vol. 11, pp. 652–661, 1916.

[2] R. W. Van der Veen, "Mineragraphy and Ore Deposition," p. 96, Figs. 91, 115, 116, 1925.

also described and illustrated many cases of repeated banding such as those of native copper and limonite, gold and limonite. Boydell [3] has applied the explanation of mutual reaction (electrical neutralization) of different sols to the case described by Knopf; Van der Veen has made free use of the same principle in the cases of banding cited by himself and Niggli [4] refers to the general efficacy of mutual reaction in sols as a cause of deposition. In the case of the banded specimen from Alacrán, described by Mr. Spurr, true solubility of the silica and sulphides involved being so small as to be incompatible with the "highly concentrated solution" assumed by Mr. Spurr and it being very doubtful whether pyrite has true solubility in molecular solution, one is compelled to suppose that the solution was colloidal, since in no other recognized form could so high a concentration of the substances involved be reached.

This being so, application of mutual reaction in colloidal solution at once suggests itself as "explaining" banding in the Alacrán specimen. That process however is not consistent with the existence of a complex solution containing all the substances involved (or their constituents) at the same time nor with the depositing powers of a solution "standing quietly in a fissure and crystallizing leisurely" as claimed by Mr. Spurr. In other words the appropriate mutual reaction in a sol would require a solution of varying composition moving slowly or intermittently through the fissure. It is not conceivable either that the complicated banding of the Alacrán specimen could be produced in any solution "standing quietly" and without circulation. The actual application of mutual reaction to the Alacrán specimen requires more assumptions than does the banding in wood tin, previously referred to. In the first place the nature of the charge on the "tuff" is not known but since most substances are negatively charged in contact with water let us assume that the charge on the "tuff" was negative. The same uncertainty exists with regard to the "silicate" but since this contains ferric iron, it may

[3] H. C. Boydell, ECON. GEOL., vol. 20, pp. 768–770, 1925; also *Trans. Inst. Min. and Met.*, 34, 1924–5, p. 315.

[4] P. Niggli, "Lehrbuch der Mineralogie," pp. 682–683, 1924.

be assumed that it was positively charged, attracted by and deposited on the tuff. The surface of the banded deposit at this stage would be positively charged against the water and consequently would attract and hold the negatively charged silica. Sulphides are usually negatively charged against water but under some circumstances the sign of the charge may be reversed. Let us further suppose the conditions of the solution were such that the charge was positive and consequently that the "black sulphides" were attracted and held by the silica band. In its turn the positively charged "black sulphides" layer would have deposited on it another negatively charged silica layer and assuming pyrite to have true "solubility" in colloidal solution, and the conditions of the latter to be such that the pyrite was positively charged, a pyrite layer would be deposited on top of the second quartz band and finally the third negatively charged silica layer was attracted and held by the positively charged pyrite. Thus there would result the banded structure described by Mr. Spurr. The assumptions made are so numerous and of such a nature that this "explanation" can only be regarded as tentative and is offered until either a more likely one is forthcoming or experimental data are available that increase its degree of likelihood. It must be understood too that the different substances would be first deposited in colloidal form and that it is assumed they later changed to the coarsely crystalline condition Mr. Spurr's description implies.

It would seem to me that the existence of the hydrous silicate of lime, ferric iron and manganese (probably of the nature of an addition "compound" formed as a result of adsorption) which apparently has not been shown to be a definite compound, cannot correctly be assumed to denote "a relatively high temperature in the ore solution" as Mr. Spurr states. Though some silicates are indicative of high temperature, they are not usually hydrous ones. The presence of such silicates as sericite, chlorite, kaolin, for example, are surely not necessarily indicative of "relatively high temperature."

Regarded from this point of view Mr. Spurr's claim (p. 536) to have "detected evidence of falling temperature during crystallization" would hardly seem to be justified.

In claiming supporting power of the ore solution for the included fragments, Mr. Spurr rejects (p. 525) the idea of high specific gravity due to high concentration and considers "the solution was in a physical condition which gave it supporting power." It seems to me that the physical condition Mr. Spurr is envisaging here must be that of a gel (in which case the ore "solution" could not strictly be considered as a *solution*) which condition would probably also be that of a "highly concentrated solution" having a specific gravity high enough to "float" the included fragments.

Mr. Spurr's reference to the Roosevelt Hotel decorative marble opens up the puzzling subject of limestone breccias in general. These occur in many places and no adequate explanation of their formation has so far been forthcoming. Mr. Spurr's description of the Roosevelt Hotel case is that of "fragments suspended and isolated in a solution which was capable of supporting them," the solution subsequently yielding the white matrix by crystallization.

It is apparent at once that this is not the only possible "explanation" and further consideration shows that it is not in agreement with certain awkward facts. There being no other proved efficaceous solvent the solution must have been an aqueous one and contained the material of the "matrix" in the form of carbonate or bicarbonate. Assuming that the matrix was present as bicarbonate, thus favoring Mr. Spurr's case since the solubility of calcium bicarbonate is greater than that of the normal carbonate, what would the maximum concentration of the solution be?

Haehnel [5] recently investigated "the solubility of calcium carbonate in water containing carbon dioxide under high pressures" and found that at 18° C. and a pressure of 56 atmospheres (the highest possible pressure for gaseous carbon dioxide at that temperature) the solubility of calcium bicarbonate is 0.64 per cent., corresponding to a solubility for calcium carbonate of 0.39 per cent. The influence of temperature on the solubility was also investigated; it was found that at a constant pressure of 56 atmos-

[5] O. Haehnel, *Jour. f. prakt. Chemie*, 107, pp. 165–176, 1924.

pheres the solubility of calcium bicarbonate rose to a maximum of 0.65 per cent. at 25° C. and then decreased to 0.42 per cent. at 55°.

It is not clear from Mr. Spurr's description in what proportion the dolomite he refers to is present in the white "matrix." In any case the solubility of magnesium bicarbonate in water saturated with carbon dioxide is considerably greater than that of calcium bicarbonate under the same conditions. At 18° C. and 18 atmospheres pressure the solution contains 13.00 per cent. of magnesium bicarbonate but on increasing the pressure up to 56 atmospheres the solubility remains constant.

With such solubilities as the probable maxima it is evident that even solutions of these relatively high concentrations could have no "suspending" or supporting (apart from the usual buoyant effect) power for the black limestone fragments and further still, that such solutions unless they were circulating, a condition expressly excluded by Mr. Spurr, were incompetent to deposit the white matrix which fills the spaces between the fragments and forms approximately 50 per cent. of the sectional area of the specimen illustrated.

As an alternative "explanation" to that of Mr. Spurr, is not the very number of the fragments, in the Roosevelt Hotel decorative marble, indicative of a loose crush breccia, the fragments of which, regarded in three dimensions and not merely in the plane of the section, were mutually supporting and originally contained between them open spaces which were later filled by percolating solutions?

What is the evidence that the solution "burst" into the black limestone as Mr. Spurr infers and that the solution was "clear" as he also states it to have been? Again, where is the evidence that the cementing solution had an expanding and a prying power? The solution would have the same pressure in the larger open spaces as in the crevices and cracks, or in other words, on both the inside and outside of the fragments, and consequently there would be no tendency to split. It would seem that if there has been any splitting, such has resulted through exertion of the

linear force of crystallization by the matrix on the small scale that the experiments of Becker and Day and also Taber have shown that force to be susceptible of.

Mr. Spurr's statement that he has "carefully refrained from discussing the origin of the dense solution in this paper, my purpose being to show that the work of water is much exaggerated in orthodox geological conceptions" is very puzzling. On page 525 he previously deprecates the idea of high specific gravity (density) accounting for the "floating" power of the solution and if water was not the solvent or dispersion medium that carried the "dissolved" or dispersed substances to their place of deposition just what was the vehicle in the examples considered in his paper and what is the medium that plays the rôle of universal solvent in geological processes usually ascribed to water?

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ANTIPATHY OF BORNITE AND PYRRHOTITE.

Sir: In this Journal for June-July, 1925, Geoffrey Gilbert points out the antipathy, in nature, between bornite and pyrrhotite and calls for observed exceptions to this rule. As I have observed an exception, its mention here may contribute somewhat to our knowledge of the subject. The occurrence was noted in 1924 during the examination, under the direction of the late Dr. W. L. Uglow, of some ore deposits on the west coast of Vancouver Island, B. C. In this locality there are a number of deposits with chalcopyrite and pyrrhotite and one with pyrrhotite and bornite. The latter is sufficiently unusual to merit a brief description.

The property is known as the Jeune group and is situated about four miles from Jeune Landing on Quatsino Sound, the most northerly sound on the west coast of Vancouver Island. The property was not being worked at the time of the examination but had been developed by stripping, open cutting, and a tunnel. The inclosing rocks of the deposit are limestone, andesitic tuff,

and diorite. The limestone and tuff belong to the Vancouver Group and are, therefore, of Triassic age. The diorite intrudes the Triassic rocks and is, therefore, probably of the same age as the Coast Range Batholith. There is a more acid intrusive near the deposit but its relationships could not be ascertained. The limestone near the diorite contact is, in part, replaced by garnet, epidote, quartz, magnetite, and sulphides. The alteration of the tuff is notably more extensive; the minerals are the same but occur in different proportions so that epidote predominates and quartz is less common. But it is in the diorite that the greater part of the mineralization occurs. Many small, irregular fractures, some of which are now filled with paper-thin veinlets, seem to have localized the metallization so that the replacement extends from them into the surrounding diorite.

The study of polished surfaces of the ore shows that the earlier metallic minerals have two modes of occurrence in the diorite. In the one case they fill the tiny fractures and form anastamosing veinlets that grade into almost solid masses of metallic minerals. The other type occurs in the vicinity of the veinlets of the first type, but the metallic minerals have selectively replaced certain minerals of the diorite and, insofar as may be seen under the highest magnification of the microscope, are not connected with the metallic minerals of the veinlets. Magnetite was the first metallic mineral to be introduced; it occurs in the fractures and replaces the ferromagnesian constituents, largely hornblende, of the diorite. Pyrrhotite followed and is observed in the veinlets and as a replacement of some hornblende, but largely as a replacement of the plagioclases. Pyrite is later and has essentially the same occurrence as pyrrhotite although it does show, probably due to its strong crystallizing power, a slightly greater tendency to replace the feldspar. Bornite cuts the magnetite, pyrrhotite, and pyrite, and occurs only in the veinlets, never in the diorite away from visible solution channels. Bornite is, in turn, replaced by chalcopyrite, chalcocite, and covellite. The latter copper sulphides occur in tiny blebs inclosed within the bornite or along the contact of bornite with other minerals ex-

cept chalcopyrite. A discussion of the hypogene or supergene origin of the chalcocite and covellite and their relationship to the chalcopyrite is beyond the scope of this paper. This is a clear case of pyrrhotite and bornite occurring together, not only in the same deposit, but in contact with one another, the pyrrhotite being earlier than the bornite.

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REVIEWS

Rocks and Rock Minerals. By LOUIS V. PIRSSON. 2d ed. Revised by ADOLPH KNOPF. vii + 426 pp., 74 figs., 36 plates. John Wiley and Sons, New York. 1926. Price $3.50.

The first edition of "Rocks and Rock Minerals" is so well known and satisfactory that it needs no description here. It was reviewed in this journal in 1909, pages 62 to 65, by Dr. Ransome who unreservedly recommends it as fulfilling its purpose of giving the elements of the subject to those who have a limited amount of time for it.

The changes in petrologic theory and tendencies in classification in the years since 1908 have made it desirable to make certain modifications which have been undertaken by Dr. Knopf, Professor Pirsson's successor at Yale. He has not greatly modified the form and scope of the original, but his experience with classes using the book has resulted in clarifying several obscure passages. The new edition is only twelve pages longer than the original, but the pages are slightly larger and the spacing and type make it more easily readable.

It is probably desirable that reviewers of textbooks should call attention to details that may be open to question, so that the author may consider whether changes should be made in future editions. Each reviewer may note different features. The one that appeals to the present reviewer as of most importance in this case is the classification of igneous rocks.

Petrographers seem to desire above all things, in the study of igneous rocks, that a classification for elementary students be arranged in such a way that group names can be retained in the same general sense in advanced work. As an example, if a student is taught in his beginning work that a diorite has excess of light-colored minerals, he will later on in his work be told to forget that teaching and believe that diorite is characterized by intermediate plagioclase without regard to whether it is more or less abundant than the dark minerals. Nearly every teacher of petrography has run against this sort of difficulty in harmonizing the elementary and advanced schemes of classification. Dr. Knopf has made a notable improvement in the classification in this book by bringing several terms into line with the more advanced microscopic definitions. Perhaps still further advances may be possible. It should be noted, however, that the text still retains some statements that seem to be based

on the classification in the first edition. Knopf writes (pages 203 and 204) that while the kind of feldspar is determined with difficulty, "it is a distinction that should always be attempted in the field," and his classification is based largely on this distinction. The reviewer believes this a proper attempt, but is surprised to find the words of the former edition repeated (on page 200) to the effect that "we cannot discriminate between the different kinds of feldspars."

Attention should also be called to a questionable usage of the term aphanite (on pages 198 and in the table at page 204), for "rocks that are nearly or wholly or stony appearance and texture, but the minerals of which cannot be determined because they are too minute." The reviewer believes that in general usage the term includes many porphyries in which the fine groundmass is not a large proportion of the rock. The loose statements in most books defining aphanite and phanerite, lead one to the impression that all the grains of phanerite (except possibly inclusions) are coarse enough to be recognized. If not all the grains are coarse (that is, if there is *any* groundmass of fine grain), it is to be contrasted with phanerite by naming it an aphanite. The glossary accompanying the CIPW classification says an aphanite is a rock wholly or in part aphanitic, implying that even a small part is enough to make it an aphanite.

As a second major feature of the book the reviewer would question the value of the space given to specific localities where rocks of a certain class outcrop. Any complete summary of the records of the important areas would occupy many volumes of the size of the one in hand. If the list is left incomplete the selection of certain areas is as likely to be misleading as valuable to the student.

A third matter for careful consideration is the process of differentiation. Both Pirsson and Knopf seem to favor the idea that a magma may in some circumstances split into two unlike liquid submagmas, and with this the reviewer has no quarrel at all. The argument for such a process, however, (page 177) is not very strong. And the arguments favoring differentiation by crystallization, and separation of crystals, are exceedingly strong. Surely the process of differentiation should not be *defined* (page 174) as a matter of the separation of submagmas, without at least a reference to the more firmly established processes of settling and squeezing out of a liquid from crystals.

Several minor points are noteworthy. Quartz and orthoclase have no true melting points (page 149) and such a mineral as anorthite would be a better illustration of the way a melting point can be reduced by water. The concentration of pyroxenic rock above the lighter rocks in the Montana laccoliths (page 171) is described as in the first edition, but Prof. R. A. Daly has argued that the upper dark rock is probably only

a chilled border phase; Professor Pirsson himself seemed to think they might be chilled phases. The fact that water in a magma is above its critical temperature does not make it gaseous when that water is dissolved in a liquid magma (page 183). Tinguaite is described in terms of the more abundant phonolite (page 257), but phonolite is apparently not defined elsewhere in the book.

A slight change is made in the definition of gneiss (page 365), omitting the reference in the first edition to the fact that most gneisses contain feldspar. While the new statement is no doubt correct it seems to the reviewer desirable to mention the occurrence of feldspar in most gneisses; it is undoubtedly true that in common usage, many coarse hornblende rocks are called schists, but differ from gneisses only in the fact that there is no prominent feldspar.

The book is well put up and should continue to be as serviceable as the earlier edition to those who are not specializing in petrography and who do not use the microscope.

FRANK F. GROUT.

Gestaltungsgeschichte der Erde. By L. KOBER. Borntraeger Brothers, Berlin, 1925. Price 7.5 marks. Pp. 200, with 60 text-figures, and a general chart.

The title of this little manual may be rendered in English *The Morphogeny of the Earth* and the volume presents in small compass a most useful summary of present knowledge and hypotheses relating to this broad subject.

Chapter I. reviews briefly the history of geology. In chapter II. are discussed the modern views on evolution and revolution in the development of the Earth. Chapter III. deals with the great events in the Earth's history. It is pointed out that this history is divisible into two vast periods—the pre-geologic and the geologic. The geologic period in turn may be divided into three phases, namely, the older geologic time, the younger geologic time, and the present. To the older geologic time belong the Archeozoic and the Proterozoic (in North America, the Paleolaurentian, the Neolaurentian and the Algonkian). To the younger geologic time belong the Paleozoic, Mesozoic and Cenozoic. The general distribution of land and sea during the various periods is outlined and illustrated by paleogeographic maps. In the older geologic time there were two periods of revolution marked by mountain building, the Laurentian revolution and the Algoman revolution. In the younger geologic time, the great mountain-forming revolutions were the Caledonian, at the close of the Silurian, and the Altaish, Hercynian, or Appalachian, in the late Carboniferous (Pennsylvanian). The mountain-build-

ing in the Cenozoic produced such chains as the Rocky Mountains, the Andes and the Alps but these uplifts were neither so nearly contemporaneous nor so widespread as those of the older revolutions.

In chapter IV. Dr. Kober takes up the development and present morphology of the individual continents and oceans. His treatment is reminiscent of the great work of Suess' but is of course in very much more compact form. He includes much new material that was not available to his great predecessor and has been remarkably successful in presenting so clear and satisfactory an outline in less than 100 pages.

The final chapter, number V., is a brief critical discussion of laws and theories that have a bearing on the morphogeny of the Earth. These include various hypotheses of continental shifting, of which Wegener's is the most recent; the theory of the permanence of the Earth's greater features; the origin of the oceans; isostasy; the origin of igneous rocks; and the problem of batholithic intrusion.

The work concludes with a bibliography.

It is to be hoped that Dr. Kober's manual may be translated into English for it would undoubtedly be found a useful and interesting summary by many who do not read German.

F. L. RANSOME.

Chemische Bodenanalyse. (Chemical Soil Analysis.) By K. K. GEDROIZ, Professor in the Forst Institute in Leningrad. Translated from Russian into German by DR. L. FREY, Riga. xxi + 245 pp. 8 figures. Gebrüder Borntraeger, Berlin, 1926.

As pointed out in the preface, the author regards soils as systems of great complexity, whose physical properties as well as fertility (chemically) are affected considerably by minute changes in chemical composition. While the well-known classical methods of Hillebrand and others apply with high precision to the analysis of silicate and carbonate rocks, they must, in many cases, be modified to become applicable to soils. The book is written primarily for the soil chemist, dealing in separate chapters with such important aspects as: Preparation of soil sample, proximate analysis of the soil as a whole, the hydrochloric acid extract, the aqueous extract, the lime requirement of soils, etc. Quantitative methods of determining certain rare elements present in minute amounts are included, such as for rubidium, cesium, lithium, zirconium, and vanadium. The author emphasizes colorimetric methods for both qualitative and quantitative estimation of certain elements, mentioning such recently published tests as the alizarin-S test for aluminum which yields a purple-red lake, and the dimethylglyoxime reagent applied to ferrous iron, the reddish-violet compound formed being sensitive to 1 part of iron in 100,000,000 parts of water! An extended chapter deals critically with the

" zeolite " and " humic acid " bases, in their relation to alkali replacement in soils and soil colloids. With the exception of a few analytical details formerly in general use but now definitely shown to be questionable or unnecessary, the book represents an accurate, painstaking, and up-to-date treatment of soil analysis, and should prove of value, not only to the soil chemist, but to the mineralogist as well.

T. F. BUEHRER.

The Geology of Oil, Oil Shales, and Coal. By MURRAY STUART. Mining Publications, Ltd. London, 1926. 104 pp.

This treatise is an attempt to furnish a connected outline of the origin and mode of accumulation of oil deposits, oil shales and coal without calling to aid metamorphism after deposition, the author's chief objection to the present theory being that it involves the loss or addition of some mineral element during the process of metamorphism, which he contends is abnormal in nature.

By experiments the author establishes the fact that oil in minute globules may be deposited with shale. From the content of oil shales he assumes that they were similarly deposited by the inclusion of spores from certain plants. His explanation of the migration of oil from shale to an overlying sandstone is ingenuous but not convincing.

The author's ideas of the deposition of coal as a sediment is taken from lectures by Professor Charles Lapworth at Birmingham University in 1906. Briefly, it is that plant debris collected in fresh water lagoons where bacteria reduced it to a black carbonaceous mud, this was carried into the sea by the draining of the lagoons, and bacterial action stopped by salt water. Duration of the bacterial action determines whether the deposit was lignite, bituminous coal or anthracite. Oil he avers may have been evolved in a similar manner by bacterial action on vegetable matter with a large oily content. His explanation of how tree trunks in normal position occur in coal beds is clever but illogical. The ideas proposed reiterate and amplify the original statements of Jukes (1865).

By an intricate chemical process, oil occurring in dolomite is explained as a sedimentary deposit, in which the oil was formed by bacterial activity on dead foraminiferal protoplasm, in a thin upper layer on the depositional floor. The presence of sulphur in dolomite oil, in his opinion explains the close association of gypsum and anhydrite with dolomite. An instance is cited where salt containing iron sulphide has been altered to anhydrite and gypsum, by weathering and consequent chemical action.

In the process of the formation of oil by bacteria, the author explains, the predominating blue color of sediments in oil fields, and the lack of

sulphide and excess of salinity in oil field waters. Torbanite and lignite are considered intermediate bacterial stages between coal and oil shales. Coal could grade laterally into oil shale or shales containing petroleum, depending on the character of the original vegetable matter.

A special variation of the author's theory is necessary to explain the occurrence of oil in the Pegu sediments of Burma, where he uses an abundance of fossil wood in the overlying Irrawaddy beds as the original vegetable debris.

Low temperature carbonization of lignite along a fault plane is given as the explanation of the occurrence of oil in the Yananma oil field. This explanation is substantiated by experiments on the lignite which yield an oil very similar to the petroleum.

The author concludes that favorable places for the accumulation of petroleum are: (1) In foraminiferal dolomite; (2) In foraminiferal or diatomaceous shale; (3) If carbon ratio is suitable in coal beds they may pass laterally into oil deposits; (4) In marine formations overlain by beds containing fossiliferous wood; (5) Where marine coal beds of proper carbon ratio have been subjected to overthrust faulting.

In a summary of future oil possibilities he states; there is slight chance in Great Britain; fairly good in Burma; recommends further work in Northwest India; slight chance in New South Wales, while Queensland with gas showings offers good possibilities.

By way of speculative geology the question is asked as to what the condition of the earth will be when the great deposits of coal and oil are again released in the air as carbon dioxide.

A well written treatise taking a few facts and by ingenuous reasoning reaching what appear to be logical conclusions. It is to be noted that natural gas, so universally associated with oil deposits, is never mentioned. The author's experience and knowledge of conditions is limited to Great Britain, Burma and India, therefore his conclusions have only local application.

A. R. Denison.

The Petrology of the Igneous Rocks. By F. H. Hatch and A. K. Wells. 8th Edition, 1926. G. Allen and Unwin, Ltd., London, and McMillan Co., New York. 566 pages. Price 15 s. net.

The new edition of this well known textbook condenses a large amount of data relating to the petrology of igneous rocks into one small volume. Its comprehensiveness is one of its most valuable features, but one questions the value of the table for the determination of minerals in thin section and the eleven pages devoted to the appearance of the minerals under the microscope. It would seem better if they were greatly enlarged or left to the more complete works dealing with those subjects.

The present edition is enlarged by the addition of a chapter on the consolidation of the igneous magmas and another on the cycles of igneous activity in the British Isles. There are also many references to the experimental work done at the Geophysical Laboratory in Washington incorporated in the text.

The same general scheme of classification of the igneous rocks which was proposed in the earlier editions is presented again and followed by a detailed description of the various rock types.

Chapters on the "Changes in Composition of the Igneous Rocks Subsequent to Consolidation" and "The Metamorphic Derivatives," coupled with an index of igneous rock names, in which those not used in the text are accompanied by a short definition, and an index of igneous rock localities complete this thorough and very useful volume.

WILLIAM M. AGAR.

YALE UNIVERSITY.

Sodium Sulphate of Western Canada, Its Occurrence, Uses, and Technology. By L. HEBER COLE. 155 pp., illus. Canada Dept. of Mines, Mines Branch Rept. 646. Ottawa, 1926.

The saline deposits in Western Canada consist chiefly of hydrous sodium sulphate (Glauber's salt) with small percentages of magnesium sulphate, sodium chloride, and related salts. Investigation of 21 deposits showed over 115,000,000 tons of hydrous salts, mainly sodium sulphate, and this report gives complete descriptions of these, and also discusses the probable mode of origin of the deposits, and the industrial uses and technology of manufacture of sodium sulphate. A method of examining the extent of individual deposits has been demonstrated, and the character of the deposits shown, thus affording a basis for future development. The report is fully illustrated with photographs, drawings, and maps.

SOCIETY OF ECONOMIC GEOLOGISTS

THE annual meeting of the Society in connection with the Geological Society of America was held at Madison, Wis., December 28 and 29. There was a representative attendance and all reported a good meeting.

At the technical session, President Bain delivered a thoughtful address on the Key Minerals in Far Eastern Industry. There followed a symposium on Zonal Arrangements of Metalliferous Deposits in joint session with the Geological Society. It was opened by Professor Emmons on the "Zonal Arrangements of Primary Metalliferous Ores," who after speaking an hour found he had only started and had to retire for the next paper by Georg Berg on "Zonal Distribution of Ore Deposits in Central Europe," presented for him by Alan Bateman. Then followed "Coincident Variations of Types of Mineralization and of Coast Range Intrusives" by A. F. Buddington and "Recent Additions to Zonal Arrangement of the Cornish Lodes" by E. H. Davison, both read by Edward Sampson. S. T. Schofield's paper on "Zonal Ore Deposits of the Coast Range Batholith" was read by title. Other non-symposium papers were: "Relations between Oxygen and Sulphur Minerals in Ore Deposits," by B. S. Butler; "Alunitic Gold Ore in the Black Hills," by F. F. Grout and G. M. Schwarz; "Ore at Deep Levels at Cripple Creek, Colorado," by G. F. Loughlin (by title); "Bauxite in Virginia," by Wilbur A. Nelson; "Use of Polarized Light in the Study of Ores," by Edward Sampson; "Subterranean Water Conditions in the Netherlands," by J. Versluys (by title); "Hypothesis of Bacterial Influence in the Genesis of Certain Sulphide Ores," by E. S. Bastin; "Pongo de Manseriche, Peru," by J. T. Singewald, Jr. (by title). Mr. DeGolyer was prevented at the last moment from attending, and his paper on "Nash Salt Dome: A Study in Prospecting by Geophysical Methods," had unfortunately to go by title.

These papers will be published in this journal when and if the manuscripts are submitted by the authors.

At the business meeting the result of the election of officers for 1927 from the recent balloting was announced as follows: President, F. L. Ransome; Vice-President, R. W. Brock; Councillors, A. C. Lawson and Alan Bateman.

SCIENTIFIC NOTES AND NEWS

Sidney Paige has returned from Colombia.

R. H. Rastall is at present in the Malay Peninsula studying the much disputed geology of the tin deposits.

A. C. Spencer, of the U. S. Geological Survey, was in Panama during December and January.

J. A. Bancroft, of McGill University, is to spend two years in study of the Rhodesian copper deposits, and will be assisted by several Canadian geologists who have specialized in the Pre-Cambrian.

R. Murray-Hughes has returned to England from Northern Rhodesia.

Fred Searls has returned to South Africa.

William M. Davis, of Harvard University, and Gilbert D. Harris, of Cornell University, are to lecture this winter at the University of Texas.

A. L. Hall, of the Pretoria Geological Survey, has been in London recently, and presented data on the base metals of South Africa before an Imperial Commission.

Kenneth K. Landes is Acting State Geologist of Kansas during the year's leave of absence of Raymond C. Moore.

James MacNaughton, general manager of Calumet & Hecla Consolidated of Calumet, Mich., has been elected president of the company, succeeding R. L. Aggasiz, retired. He will continue his residence at Calumet.

A. E. Drucker has been made Dean of the School of Mines and Geology at Washington State College, Pullman, Wash.

H. J. Hawley, of the geological department of the Standard Oil Company of California, is chairman of the Pacific Coast Section of the American Association of Petroleum Geologists.

D. Dale Condit, geologist in charge of petroleum exploration in British India for the Whitehall Petroleum Corporation, Ltd., may be addressed in care of the London Office, 53 Parliament Street, London, S. W. 1.

R. A. Daly, of Harvard University, has been ill of late and is temporarily relieved of active teaching.

R. D. Reed, formerly of 1021 Forest Court, Palo Alto, has removed to 1717 South Third Street, Alhambra, California.

R. D. Vernon is now chief geologist for the Mexican Eagle Oil Company at Tampico.

Roscoe Reeves, of the U. S. Geological Survey, has been furloughed for six months to work in South America.

Mowry Bates, well known as a petroleum geologist, died November 17 at his home in Venice, California, aged 51 years. He was located in Tulsa, Oklahoma, for a number of years.

E. C. Andrews is expected at New Haven within the next month or so to deliver the Silliman lectures at Yale University.

D. H. Hewett is expected to return in March from his field work in Nevada to his U. S. Geological Survey office at Washington.

Sydney Ball left in January for a three-months professional trip to South America.

W. H. Emmons is engaged by the Mining Corporation of Canada to examine the company's holdings in the Rouyn area, Quebec.

B. B. Nieding, general manager of the Kennecott Mines, has been in Seattle recently and made a trip to the Coeur d'Alene Mines.

The Interior Department of the U. S. Geological Survey announces that potash beds of sufficient thickness and content to be mined, should market conditions be favorable, have just been discovered by core drilling by the Snowden McSweeney Company in Eddy County, New Mexico. Polyhalite is the most abundant mineral, but four beds of sylvite and a 17-inch bed of langbernite with associated kainite and halite, are potentially workable. The most promising beds are 7½ feet thick at 988 feet depth, and contain two bands of polyhalite 2.7 and 2.5 feet that would sort to average 14.6 per cent. K_2O.

The American Association of Petroleum Geologists will hold its Twelfth Annual Meeting in Tulsa, Okla., March 24–26. The program is being arranged as follows: (1) Papers on new fields in active development; (2) general papers; (3) symposium of the relation of structure to petroleum accumulation. A special session for Paleontology will be held Friday morning, and one for Geophysical papers Friday afternoon. Program information may be obtained from Sidney Powers, Box 2022, Tulsa, Okla.

The Third Pan-Pacific Science Congress was held at the Imperial University of Tokyo, Japan, October 30 to November 11. All the Pacific countries were represented by two hundred foreign delegates, and there were four hundred Japanese delegates. The Japanese Government was lavish in its entertainment, and all the numerous excursions preceding and following the Congress were free to the overseas delegates. Excursions included the North Island of Japan, Tarumai Volcano, Nikko, Hakone, Central Japan, Inland Sea, and Kyushu. More than four hundred papers were presented, in English. Oceanology, Seismology, and the geological sciences were emphasized. The excellent seismographical instruments of Japan were studied. The next Congress will be held in Java in 1929.

The Geological Society of America held its thirty-ninth Annual Meeting at Madison, Wis., Dec. 27–29. There was an attendance of over 300, including the membership of the Mineralogical Society, Paleontological Society and Society of Economic Geologists. The buildings were well suited for the meetings and the nearby dormitories gave comfortable lodgings. The success of the meeting was in no small part due to the efforts of the Local Committee. Some 83 papers were presented or read by title before the Geological Society, 22 before the Paleontological Society, 28 before the Mineralogical Society, and 14 before the Society of Economic Geologists. The main feature of the meeting was the Symposium on Pre-Cambrian Geology, and for this the Canadian members came down in force armed with weighty discussion. A. C. Lawson gave his Presidential address on Folded Mountains and Isostasy. At the banquet Professor Leith presided as toastmaster. Among the speakers were Mr. Keith, the incoming President, and Messrs. Coleman, Chamberlain, Wrather, Nelson and Lawson.